PB-224 476

PILOT PLANT DEMONSTRATION OF A LIME-BIOLOGICAL TREATMENT PHOSPHORUS REMOVAL METHOD

Lawrence Schmid

Kansas State University

Prepared for:

Environmental Protection Agency

June 1973

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

W74.00155

PB 224 476

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

3. Accession No. W74-00155

4. Title PILOT PLANT DEMONSTRATION OF A LIME-BIOLOGICAL TREATMENT PHOSPHORUS REMOVAL METHOD,

7. Author(s)
Schmid, Lawrence

9. Organization
Kansas State University, Manhattan,
Department of Civil Engineering.
~~Manhattan, Kansas 66506~~

10. Project No. EPA Project
17050 DCC

11. Contract/Grant No.
~~17050 DGC~~

15. Supplementary Notes
Environmental Protection Agency, report ~~number~~, Technology Series.
EPA-R2-73-159, June 1973. 48p, 16 fig, 2 tab, 12 ref

16. Abstract A 15,000 gpd pilot plant was constructed to demonstrate the capabilities of a lime treatment process for phosphorus removal. The lime treatment of raw wastewater removes the bulk of the phosphorus, and a subsequent biological process removes an additional increment of phosphorus via cell synthesis.

The pilot plant used for the study was a package-type, prefabricated unit. Additional small tanks were provided for sludge storage and measurement. A variable speed motor was mated to a program controller to duplicate a diurnal flow pattern through the pilot plant. Lime was introduced into the raw wastewater in response to an automated pH control system. Instrumented systems were also developed for turbidity and ortho-phosphate concentrations in the plant effluent. The raw wastewater entering the pilot plant was obtained from the wet well of the Manhattan, Kansas Municipal Plant.

Lime treatment of raw wastewater to a pH of 9.5 to 10.0 resulted in phosphorus removal of about 80 percent in the primary clarifier. The removal of BOD at this pH level was about 60 percent as compared to 35 percent normally expected in primary settling. The biological activated sludge process following the lime treatment neutralized the primary effluent due to the microbial carbon dioxide production. Aerator pH's were in the neighborhood of 8.0.

Lime treatment prior to biological treatment resulted in a change of the settleability of the mixed liquor. Rather high sludge volume indexes were routinely encountered. The process is capable of 90 percent phosphorus removal; however, consistent removal is only assured at the 80 percent level. (EPA)

17a. Descriptors
*Nutrient Removal, *Chemical Coagulation, *Biological Treatment, Sludge, Municipal wastes, Wastewater, Biological Oxygen Demand, Pilot plants, Instrumentation, Turbidity, Treatment, *Phosphorus, Lime

17b. Identifiers
~~*Instrumentation~~, Diurnal Flow, ~~Turbidity~~, Program Controller, Respiration Rate, Phosphate Analyses, *Lime treatment

17c. COWRR Field & Group 05D

73-159
Available from GPO Sup Doc as EP 1.23/2:, $0.85 ; microfiche from NTIS as PB ~~[illegible]~~. $1.45

18. Availability L

~~19. Security Class (This Report)~~ ~~20. Security Class (This Page)~~ ~~21. Price~~

Send To:
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
U.S. DEPARTMENT OF THE INTERIOR
WASHINGTON, D. C. 20240

Abstractor E. F. Barth | Institution NERC-Cincinnati, Ohio

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

Details of illustrations in this document may be better studied on microfiche.

59

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Monitoring, Environmental Protection Agency, have been grouped into five series. These five broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The five series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

EPA-R2-73-159
June 1973

PILOT PLANT DEMONSTRATION OF A LIME-BIOLOGICAL TREATMENT PHOSPHORUS REMOVAL METHOD

By

Lawrence Schmid
Kansas State University
Manhattan, Kansas 66506

Project 17050 DCC
Program Element 1B2043

Project Officer

Edwin F. Barth
Biological Treatment Research Program, AWTRL
Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Prepared for

OFFICE OF RESEARCH AND MONITORING
U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price 85 cents domestic postpaid or 60 cents GPO Bookstore

EPA Review Notice

This report has been reviewed by the Office of Research and Monitoring, Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

A 15,000 gallon per day pilot plant was constructed to demonstrate the capabilities of a lime treatment process for phosphorus removal. The process consists of lime treatment of the raw sewage with settling of the resultant phosphorus-rich sludge in the primary clarifier. This is followed by an activated sludge process where much of the remaining phosphorus is incorporated into cell mass and subsequently removed.

Lime treatment of the raw sewage to a pH of 9.5 to 10.0 resulted in phosphorus removals within the primary clarifier of about 80 percent. The removal of BOD at this pH was about 60 percent as compared to the 35 percent normally expected with settling alone. The biological process following lime treatment neutralized this high pH due to microbial carbon dioxide production down to pH 8.

Lime treatment prior to biological treatment resulted in a change of the microbial life within the aeration tank over that normally expected. The resultant higher sludge volume index must be taken into consideration in design.

The process is capable of achieving removals of 90 percent of total phosphorus; however, consistent removal is only assured at the 80% level.

This report was submitted in fulfillment of Project Number 17050 DCC, under the (partial) sponsorship of the Environmental Protection Agency by the Kansas State University, Department of Civil Engineering, Manhattan, Kansas 66506.

CONTENTS

	Page
CONCLUSIONS	1
INTRODUCTION	3
DESCRIPTION OF FACILITIES	7
RESULTS	15
MISCELLANEOUS STUDIES	37
DISCUSSION	39
ACKNOWLEDGMENTS	41
REFERENCES	43
APPENDICES	45

Preceding page blank

FIGURES

No.		Page
1.	Phosphorus Removal versus Lime Addition	5
2.	Schematic of Proposed Flow System	6
3.	Schematic of Pilot Plant	8
4.	Pilot Plant	9
5.	Flow Control Device	10
6.	Flow Measurement Apparatus	12
7.	Flow Variations with Time, Manhattan Plant	16
8.	COD Variations with Time, Manhattan Plant	17
9.	SS Variations with Time, Manhattan Plant	18
10.	Phosphorus Variations with Time, Manhattan Plant	19
11.	Phosphorus Removal versus Primary Effluent pH	21
12.	Primary Effluent pH versus Lime Dosage	23
13.	Primary COD Removal versus pH	25
14.	Primary SS Removal versus pH	26
15.	Primary Sludge Production versus pH	31
16.	Chemical Sludge Filtration Rate versus Polymer Dosage	33

TABLES

No.		Page
1.	Average Wastewater Characteristics for Manhattan, Kansas	15
2.	Alkalinity, pH, and Hardness of Manhattan Wastewater	20
3.	Lime Dosage Variations for Different Periods of the Day for a pH of 10.5	22
4.	Typical Turbidity Analyses at pH 9.4	27
5.	Effect of Lime Treatment on Chemical Characteristics through Plant	28
6.	The k_1 Reaction-Rate Constants	35
7.	Ratios of Lime Treated Sewage k_1 values to Settled Sewage . . .	36

CONCLUSIONS

1. Lime treatment of raw sewage preceding biological waste treatment is a workable method for phosphorus removal. The process is capable under good conditions of 90 percent phosphorus removal. At a pH greater than 9.5 removals of 80% were almost always assured. The phosphorus concentration of the wastewater under test was reduced from around 10 mg/l down to about 1 mg/l. A minimum pH of 9.8 was required to obtain these removals.

2. The addition of lime to the raw sewage to a pH of 9.8 resulted in BOD removals through the primary system of about 60 percent as compared to 30 to 35 percent removals without lime. Suspended solids removals did not increase much although much of the solids in the primary effluent was chemical precipitate which redissolved in the lower pH of the aeration tank.

3. The microbial production of carbon dioxide within the aeration tank is sufficient to neutralize the lime added in the primary system, even when primary pH values up to pH 11 are used.

4. The lime treatment process has consistently resulted in a change of microbial life within the aeration tank over that normally expected. The rate of waste stabilization is not decreased, but a more voluminous sludge is produced. With allowances for this, it should not prove to be a serious hinderance to the process.

5. The lime treatment process produces two to three times more sludge than would be produced in a conventional secondary treatment plant. Howeyer, with proper polymer treatment the sludge can be easily and economically dewatered.

6. The recommended sludge treatment scheme would be polymer treatment, vacuum filtration, or centrifugation, and then incineration and/or landfill.

7. Lime feed and control is not a highly critical operation so long as the pH is greater than 9.5 to 9.8. Overfeeding up to a pH of 11 does not affect the process and will only result in more sludge production and the wastage of lime.

8. Primary clarifier surface overflow rates did not appear to be highly critical for effective phosphorus removal from the primary unit. Most of the floc is heavy and settles rapidly. However a residual fluffy floc still will not settle well even down to overflow rates of 300 gpd/sf.

9. The addition of polymer to the lime treated raw sewage, either before, during, or after lime treatment did not result in any significant increase in phosphorus removal through the primary unit.

INTRODUCTION

Removing phosphates from sewage at the waste treatment plant rather than from the products making up the sewage, is a philosophy which is receiving increased attention. The difficulty in finding a phosphate substitute for detergents and the realization that removal from detergents will only result in a partial solution to the problem has again focused attention on phosphorus removal at the treatment plant.

Phosphorus quantity in sewage has increased almost four fold in the last twenty years, due mainly to the use of synthetic detergents. These quantities are substantiated both in the sanitary engineering literature and in industrial phosphate production statistics.

Phosphorus removal was first attempted by the removal from final secondary effluent (1)(2). This resulted in high chemical costs and, where lime was employed, recarbonation to lower the pH after chemical precipitation had to be practiced. The emphasis switched to removal by biological means, either by algae (3), or by the activated sludge organisms as "luxury up-take" (4)(5). These methods have not provided consistently good removals. Emphasis has recently been placed on chemical precipitation of the phosphates in the activated sludge aeration chamber (6)(7). This offers some advantages of operation but the chemical costs are still quite high.

Rather than adding an additional process to a conventional plant, a systems approach, integrating the entire treatment system, seemed to be the logical way to proceed. Since the phosphate is precipitated readily by a variety of chemicals, it seemed essential that a chemical process should be a part of the overall system.

Based on a review of the literature and jar tests in the laboratory, lime was selected as the best coagulant from the standpoint of both cost and efficiency. An examination of a typical curve, Figure 1, where phosphate remaining is plotted against lime addition, yields the answer to the reasoning behind the proposed process. The general shape of this curve is applicable whether the wastes used are treated or untreated.

If 95% phosphorus removal from the wastewater given in Figure 1 is desired, it will be necessary to reduce the phosphate concentration from 11.5 mg/l, point A on the curve, to 0.6 mg/l, point C. From a practical viewpoint it can be seen that the initial lime dosage is quite effective in removing relatively large quantities of phosphorus. As the phosphate concentration is reduced to a low level, below 3 mg/l, the lime dosage required to remove a unit of phosphorous begins to increase quite rapidly. For this reason lime treatment can best be used to remove the initial fraction of phosphate from the wastewater.

The micro-organisms in activated sludge can readily utilize phosphorus at very low concentrations. Uptake of phosphorus by the micro-organisms in biological waste treatment systems is related to the amount of cells synthesized which in turn is related to the organic load stabilized.

Preceding page blank

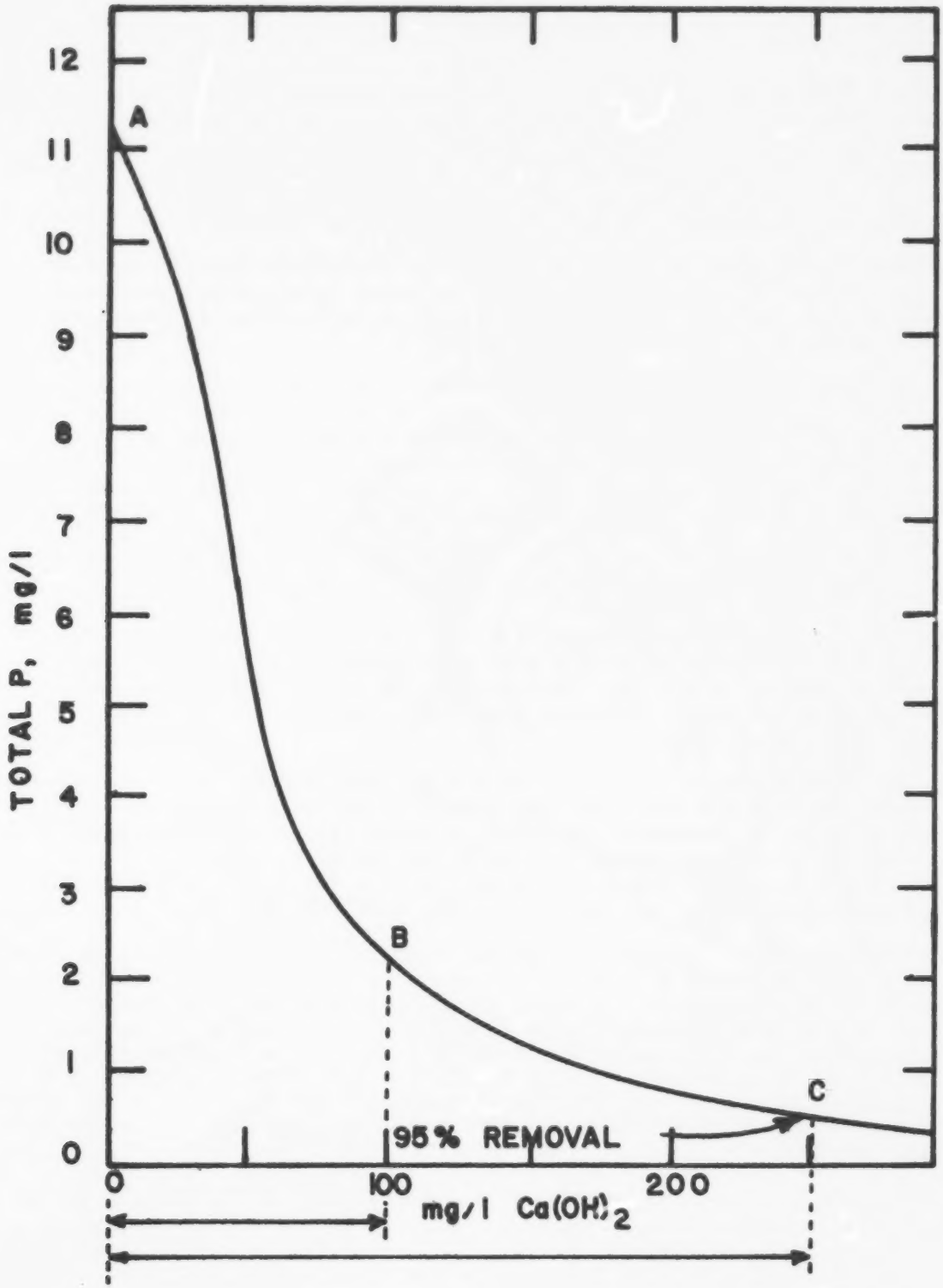

Fig. 1 Phosphorus Removal versus Lime Addition

Combining these two concepts it is immediately apparent that lime treatment should precede rather than follow biological treatment for the most economical design. By adding 100 mg/l lime to the wastewaters in Figure 1, it would be possible to drop the phosphate concentration to 2.3 mg/l, point B on the curve. Thus, the lime treatment effects a 79% phosphate reduction. It would have required 150 mg/l more lime to obtain an additional phosphate removal of only 16%, 0.6 mg/l. Biological treatment can be just as effective at a phosphate concentration of 2.3 mg/l as at 11.5 mg/l. In essence, the microbes are used to remove that fraction of phosphates which require large chemical dosages. A schematic diagram of the proposed flow system is presented in Figure 2.

Initial laboratory research demonstrated that this phosphorus removal method appeared to offer an economical solution to the problem. The purpose of this research was to expand the laboratory study to include larger scale pilot plant testing. The primary objective of this investigation was to develop design and operating criteria for this recently developed phosphate removal method of lime precipitation prior to biological treatment. Exploration of expected operating problems, process sensitivity, and reliability were also objectives of this investigation. Besides functioning as a phosphate removal process, the process was to be examined as a treatment scheme which may extend the useful life of overloaded plants, to handle slug loads, and for other situations where a coagulant aid for sewage would be required.

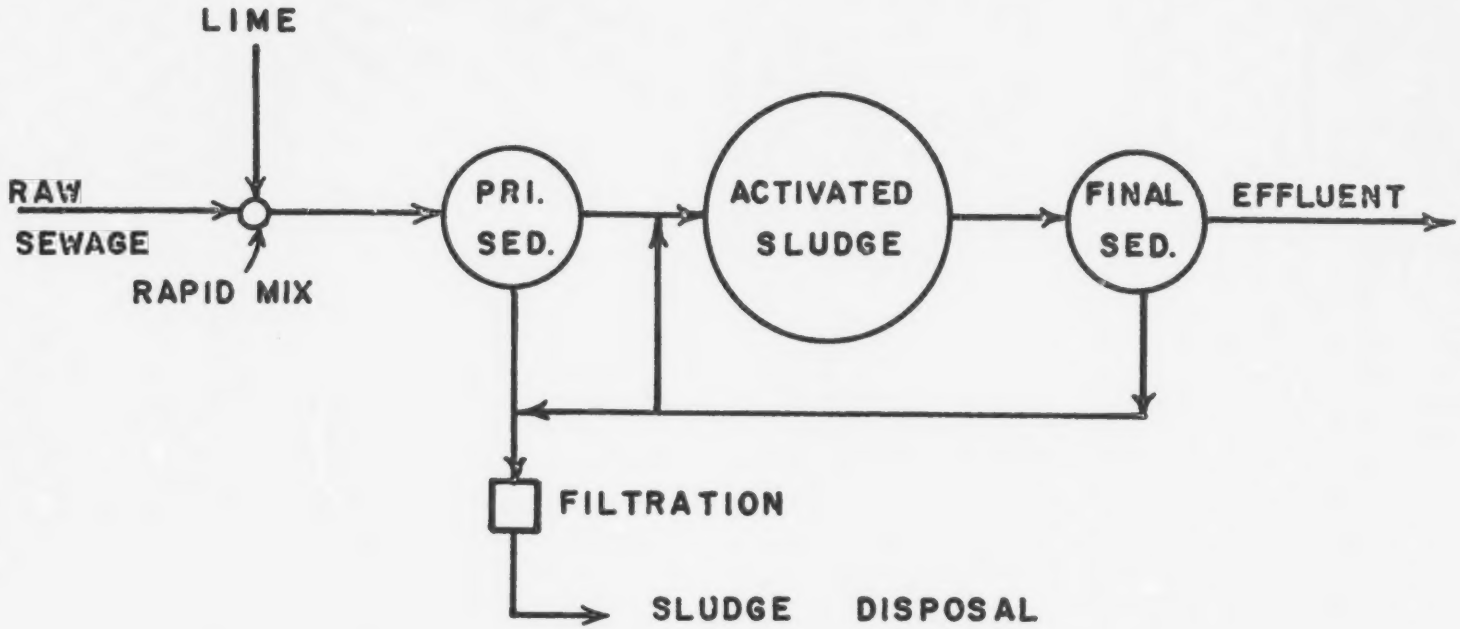

Fig. 2 Schematic of Proposed Flow System

DESCRIPTION OF FACILITIES

The research was conducted with a 15,000 gallon per day activated sludge pilot plant which was erected at the Manhattan, Kansas Waste Treatment Plant. Figure 3 is a schematic of the set-up and Figure 4 is a photograph of the pilot plant. Many equipment modifications were made during the early part of the project. The final modifications will be reported upon.

The raw sewage is pumped from the inlet well of the Manhattan Sewage Treatment Plant clarifier by a variable speed positive displacement pump. This pump operates under approximately five feet of suction. The pump is a Jabsco Model 6400, rubber impellered, positive displacement type. The pump is modified by removing the guard teeth within the pump on the in-let and out-let sides. The pump was belt driven by a 1-HP variable speed motor. The suction line from the clarifier to the pump was 1 1/2 inch in diameter. To capture unusally large solids which might plug the pump and to prevent loss of prime on the pump a 30 gallon air tight container was installed immediately prior to and in line with the pump. A vacuum pump was attached to this tank to withdraw captured air withdrawn with the sewage from the primary clarifier and to maintain a water level above that of the sewage pump. The vacuum pump operated in response to a signal from a mercury float switch within the tank to maintain a constant level. This tank was equipped with a snap-off lid so that the accumlated solids and floatables could be removed at a weekly interval.

The pumping rate was controlled by a program controller to simulate the variable flow of sewage that would be expected to a treatment plant under gravity flow conditions. A 24 hour clock with an attached cam operated a lever connected by flexible wire to a counter weighted pulley attached to the motor speed control knob. This system is more fully described in an article published by the project director (8). A photograph of the system is shown in Figure 5. Lime slurry was injected into the line following the pump and immediately before the waste entered a 20 gallon reaction tank (20 gallon water system pressure tank). Following this tank were the immersion type pH electrodes. The tank allowed reaction time for the lime and resulted in some flocculation. A Speedomax-H pH Meter, recorder and controller by Leads and Northrup was the heart of the pH control. pH was sensed by the immersed pH electrodes equipped with automatic temperature compensator. The pH was recorded. A controller operated a variable speed tubing pump which injected a lime slurry into the line depending on whether the actual pH was above or below the controller set point. The controller never did function to give good variable control, but operated only as an on-off device. This, however, appeared satisfactory even though some over shoot of pH always occurred. Lime was prepared in a 50 gallon barrel equipped with an 8 inch motor driven propeller to maintain lime in its slurry form. This can also be seen in Figure 5. A 50 pound bag of hydrated lime was mixed with 50 gallons of water as required. Lime usage was determined by measuring the drop in slurry level.

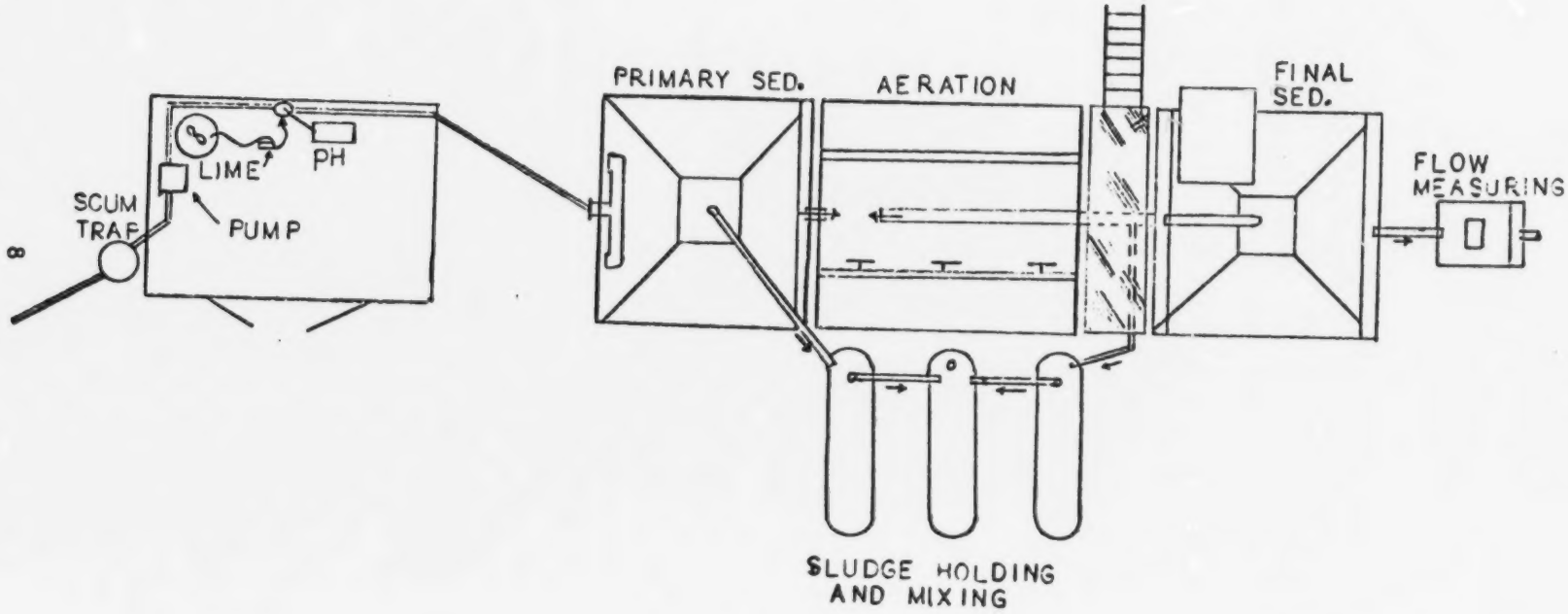

Fig. 3 Schematic of Pilot Plant

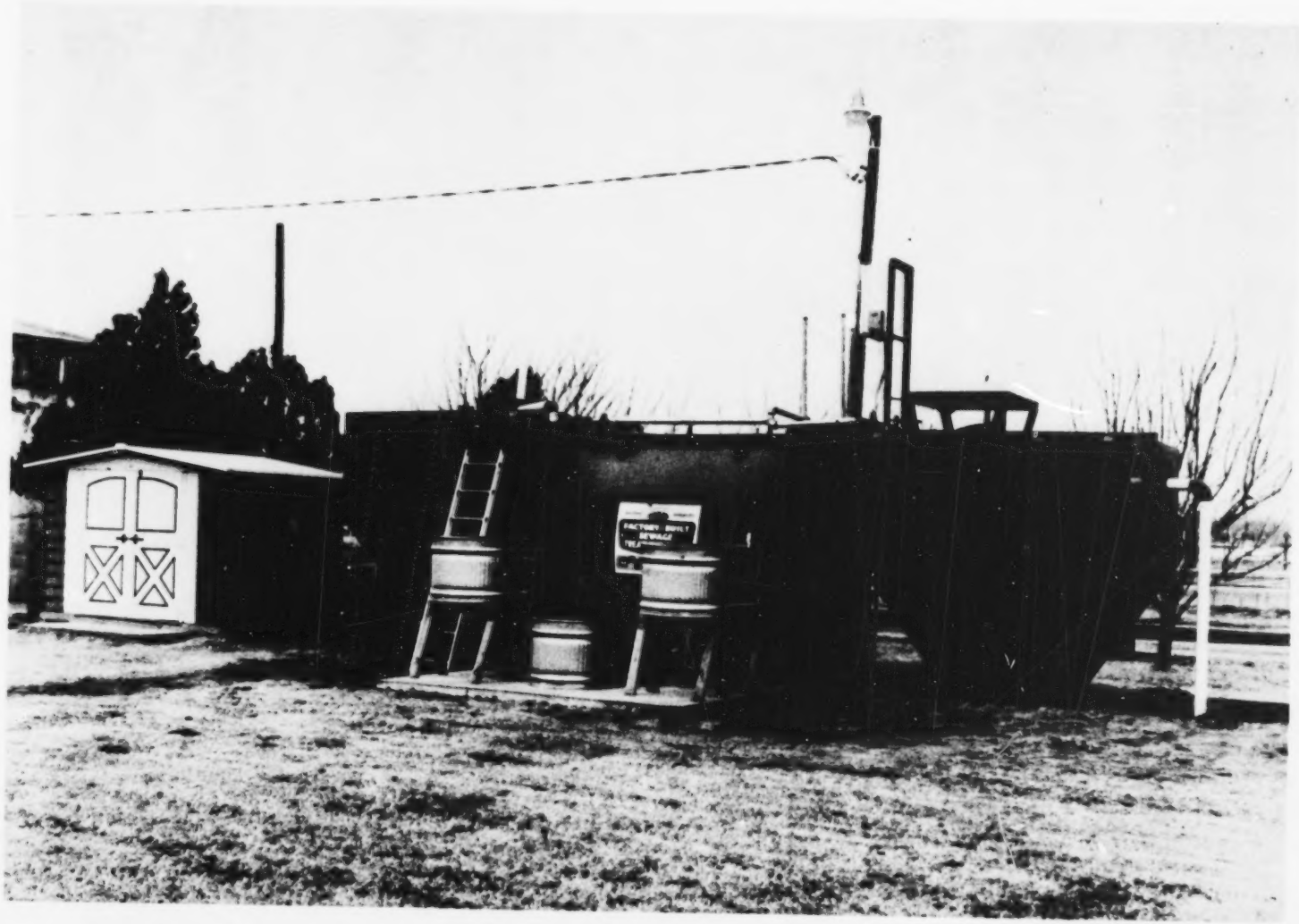

Fig. 4 Pilot Plant

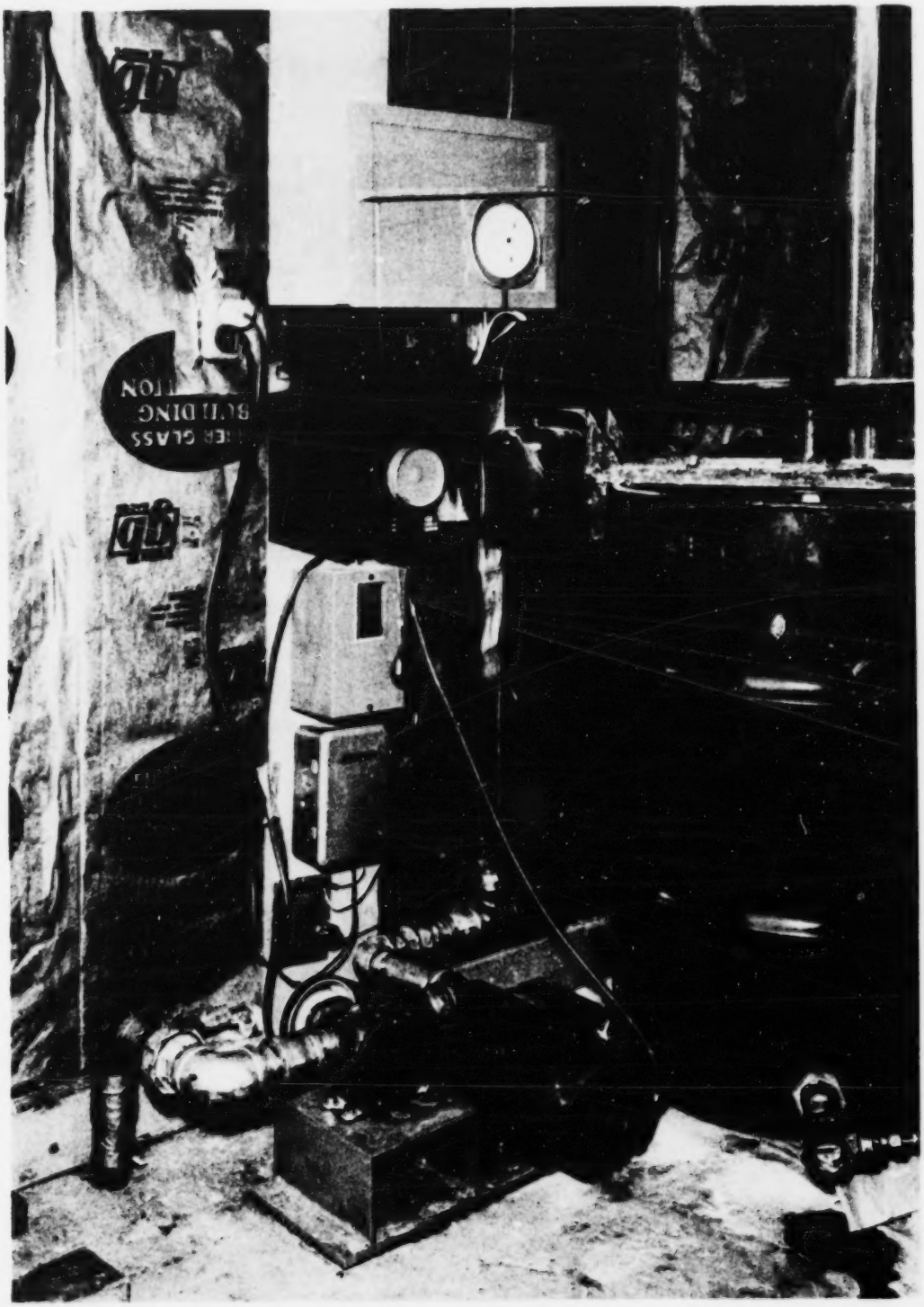

Fig. 5 Flow Control Device

The lime treated sewage entered the primary settling tank which was an 8' x 8' hopper bottomed clarifier. At a 20,000 gallon per day design flow the over flow rate would be 300 gallons per day per square foot. Settled sludge was pumped from this tank automatically on an hourly basis by an air lift pump.

Supernatant flowed over a V-notch weir to the aeration tank. The aeration tank is a 3,000 gallon cylindrical tank, 8' in diameter and 8'4" long. Air is supplied to the tank through rubber boot diffusers supplied by Smith and Loveless Corporation. Two 2-HP blowers, each delivering 55 cubic feet per minute at 3.5 psi are provided. One blower is adequate to furnish sufficient oxygen so that the blowers can be alternated in usage.

The final clarifier is an 8' x 8' hopper bottom clarifier, identical in size to that of the primary clarifier. Activated sludge return is accomplished by a continuously operating air lift pump which can be controlled by a ball valve. An air lift scum return device is used to transfer any scum back to the aeration tank. Activated sludge is wasted by a 1 1/2 inch tap into the activated sludge return pipe. Wasting is done manually by means of a gate valve. The flow is measured in a weir box just prior to discharge to the plant sewer. The weir is a 22 1/2 degree V-notch. The flow recording device is a Stevens Model 61-R Flow-Meter with continuous strip chart recording in gallons per day and equipped with a continuous volume totalizing display. The recorder is run by an 8 day spring wound clock and is equipped with a 30 day chart. Figure 6 is a photograph of the weir box.

Raw sludge from primary settling can be pumped into a 200 gallon stock tank where it can be held for measurement. This was the method for determining sludge quality and quantity. An entire days production could be captured and sampled. Waste activated sludge could also be drained into a similar tank for flow measurement and sampling. The two type of sludges could be blended into a third tank for further studies. These tanks can be seen in the photograph, Figure 4.

Instrumentation.

The turbidity of both the primary effluent and the final effluent was continuously monitored. Due to the coating tendency of lime a surface scatter turbidimeter was thought to be the only feasible method. A Hach continuous reading surface scatter turbidimeter was selected for this. The turbidity was continuously recorded with a 2 inch Rustrak strip chart recorder. The primary and final effluents were siphoned by a 1/2 inch plastic tubing back to the control building at a rate of 1/4 to 1/2 gpm.

A device was constructed to direct the flow of either the primary effluent or the final effluent to the turbidimeter for a period of one hour. At the end of one hour the turbidimeter chamber was automatically emptied and the flow from the other effluent source returned to it. Thus, both effluents could be monitored with one instrument. A Hach Model 31, continuous recording phosphate analyzer was also installed to take the same flow that was going to the turbidimeter. This system operated on a colormetric

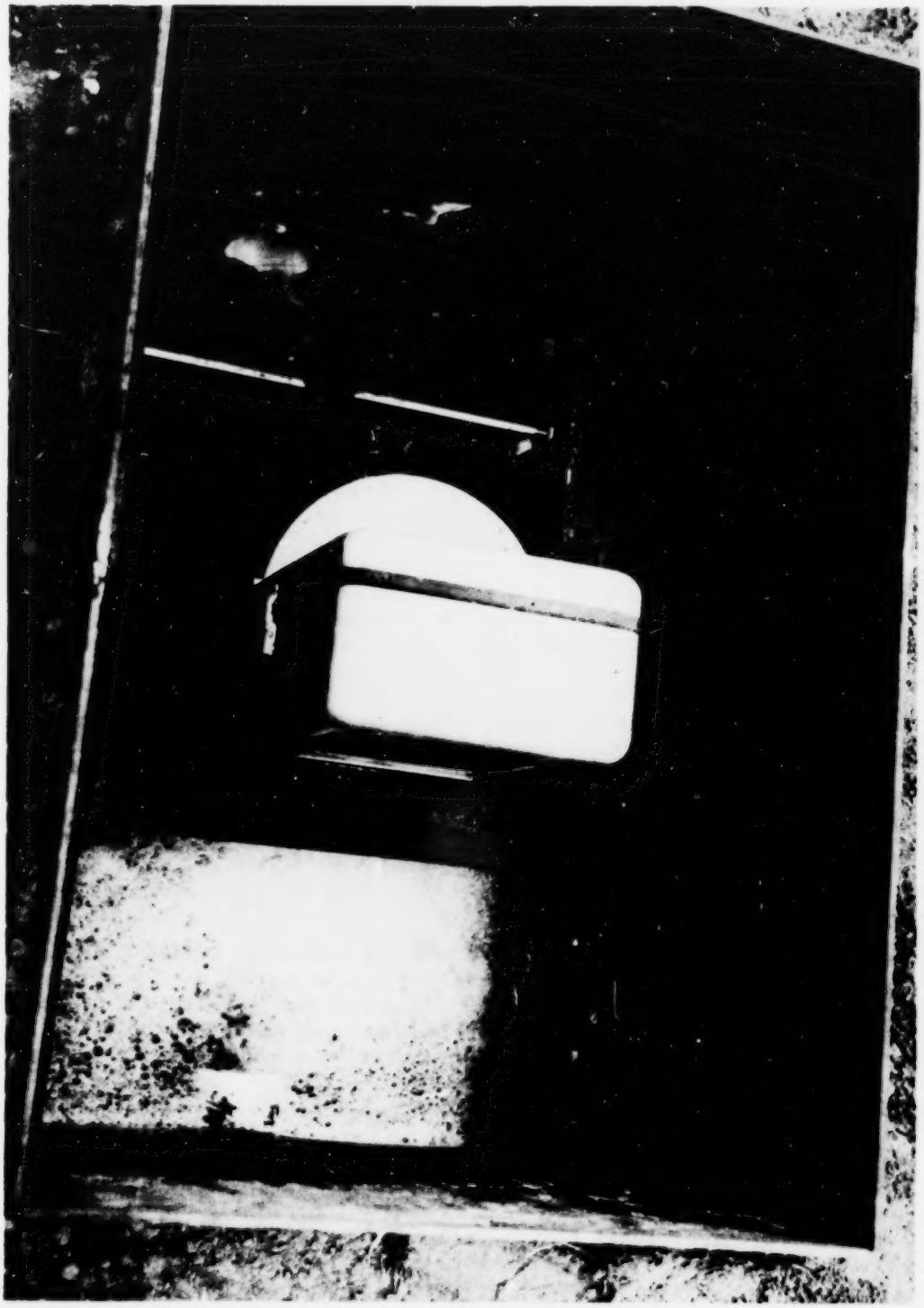

Fig. 6 Flow Measurement Apparatus

method with the Aminonaphtholsulfonic Acid method for ortho phosphate. Results were printed out on a 2 inch Rustrak recorder. Since it was a colormetric procedure interferences could be expected due to solids present. Also, it was recognized that only ortho phosphate would be measured. The installation of this machine was not designed to eliminate laboratory analysis but only to monitor the effluents for any sudden changes in ortho phosphate concentrations. Daily maintenance was required on both instruments to keep them functioning. The major problem was build-up of solids and slime because of biological solids in the secondary effluent.

Operational Problems.

As with any other pilot research facility, this plant was not without its operational problems. Some would only occur with a plant of this size while others could be expected in a full scale plant. As long as a large solids trap was ahead of the pump, plugging by large sewage solids and rags was no problem. A Jabsco pump was very reliable and very seldom plugged. The 20 gallon reaction tank for lime additions was a source of problems. Solids and matted hair eventually resulted in plugged lines. This problem necessitated an occasional cleaning. The line following lime addition was a 1 1/2 inch ABS plastic line. This would coat with precipitate and would eventually plug. Every three to four weeks the line had to be flushed with acid to clean it out. Similar problems may be expected in a large plant. Coating of the primary effluents weirs was also encountered. This could be cleaned with a hose which is normal maintenance anyway at existing plants.

The pH electrodes were also subject to this lime fouling. Several days accumulation resulted in loss of sensitivity. The electrode assembly was removed about every two days, dipped into acid which quickly removed the deposits, and returned to service. Calibration was checked weekly but it usually did not require adjustment.

Another problem encountered in this plant was that the sludge did not settle well in either the primary or the final tank. The solids tended to cling to the 60° sides or the solids would bridge over near the sludge pump inlet. If the interior sides of the settling tanks were not cleaned at least every other day by high pressure water, septic sludge resulted in the primary, and denitrification occurred in the secondary. This resulted in a large amount of floating solids occurring in both tanks. This was not a fault of the process but instead was the fault of the equipment. In summary the major operational problem which can be attributed to the system itself is the lime fouling of both the monitoring and control equipment.

RESULTS

Pilot Plant Influent Wastewater Quality

The influent wastewater for the pilot plant was raw sewage from the city of Manhattan, Kansas. The city of Manhattan serves a sewered population of approximately 40,000. Kansas State University with its student population of about 15,000 is included within this figure. There is very little industry within this town so industrial wastes are a very minor constituent of the wastewater. This sewage can be classified as primarily domestic.

Samples of Manhattan wastewater were collected from June 1970 through August of 1971. Samples were generally taken twice weekly and were collected at the hours of 3:00 P.M., 9:00 P.M., 3:00 A.M. and 9:00 A.M. Analyses were normally run on each sample and a composite value calculated according to flow. At times the samples were composited first and a single analyses run. The following results in Table 1 are the averages of the raw sewage samples showing the variations throughout the day.

Table 1. Average wastewater characteristics for Manhattan, Kansas.

Time	COD mg/l	SS mg/l	Total P mg/l
3 AM	270	100	7.71
9 AM	395	185	8.63
3 PM	575	215	12.17
9 PM	510	225	10.34
Calculated Composite Based on Typical Flow	465	195	10.01

These were then composited according to a typical plant flow, Figure 7, to give the calculated composite values. Figures 8, 9, and 10 depict some variations from two sampling runs with samples collected hourly. These values are in very close agreement with the values of Table 1. Analyses were made periodically throughout the study to determine the hardness, alkalinity, and pH of the Manhattan wastewater. The average composite values are reported in Table 2. These values did not change greatly over the period of the study.

Preceding page blank

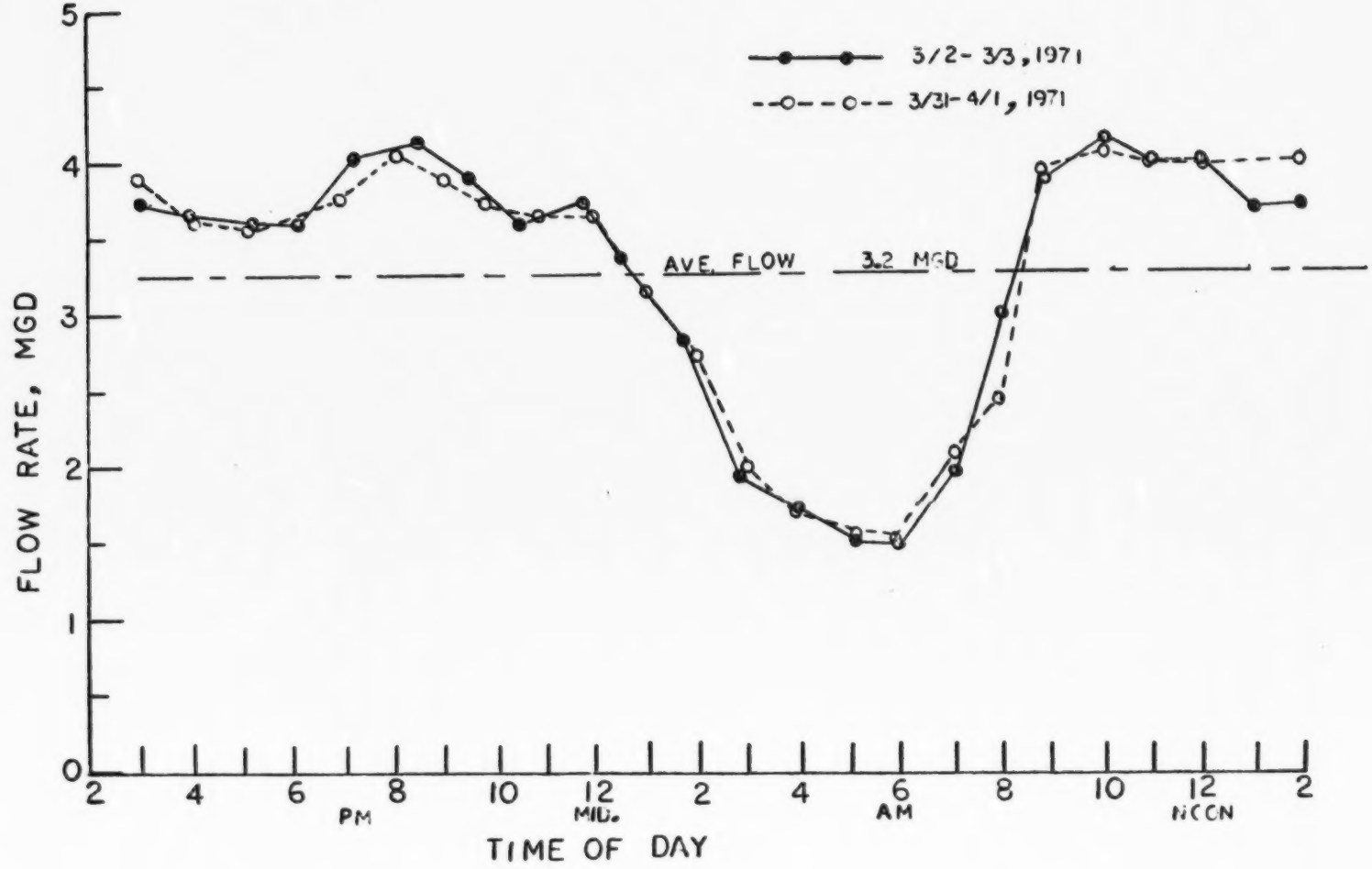

Fig. 7 Flow Variations with Time, Manhattan Plant

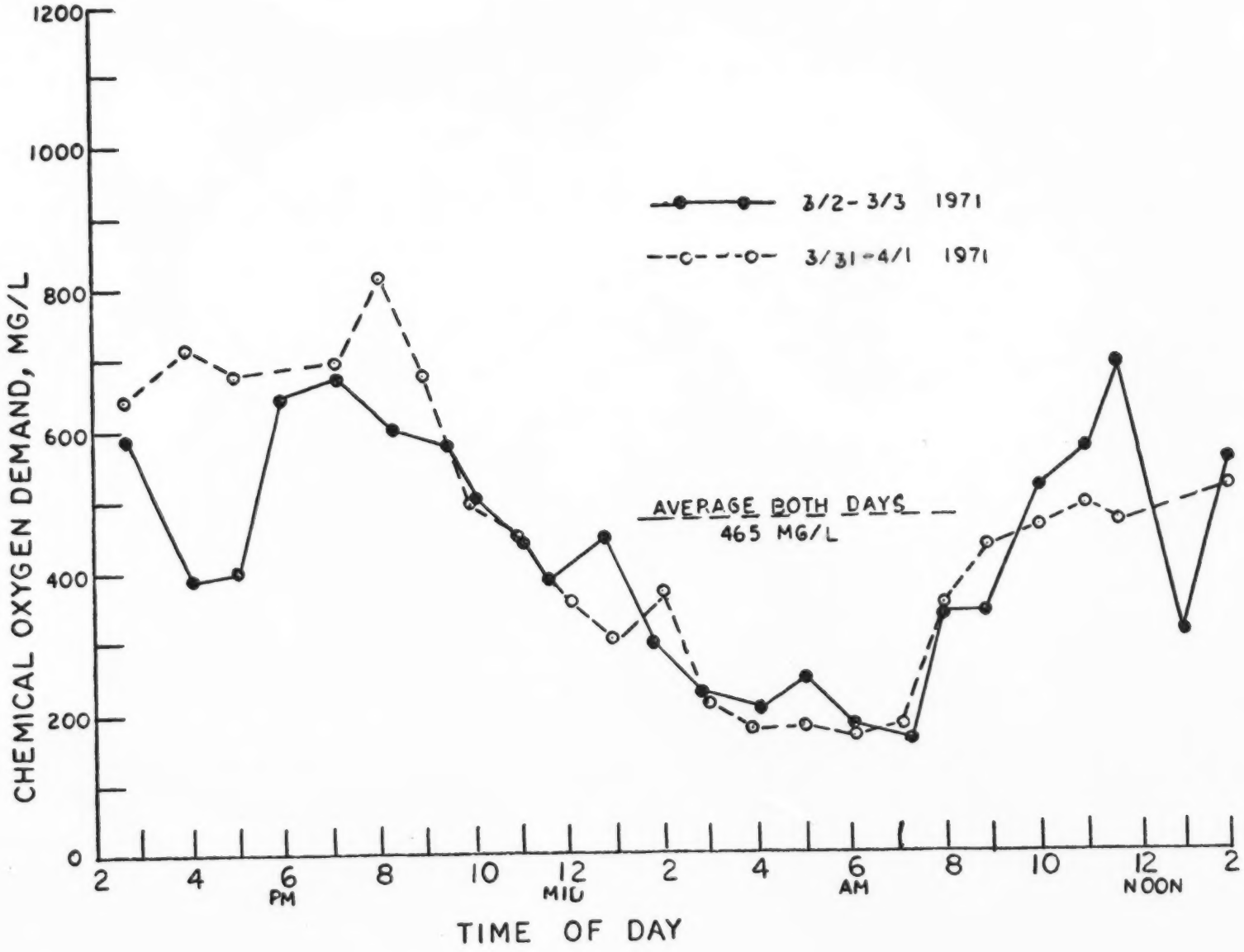

Fig. 8 COD Variations with Time, Manhattan Plant

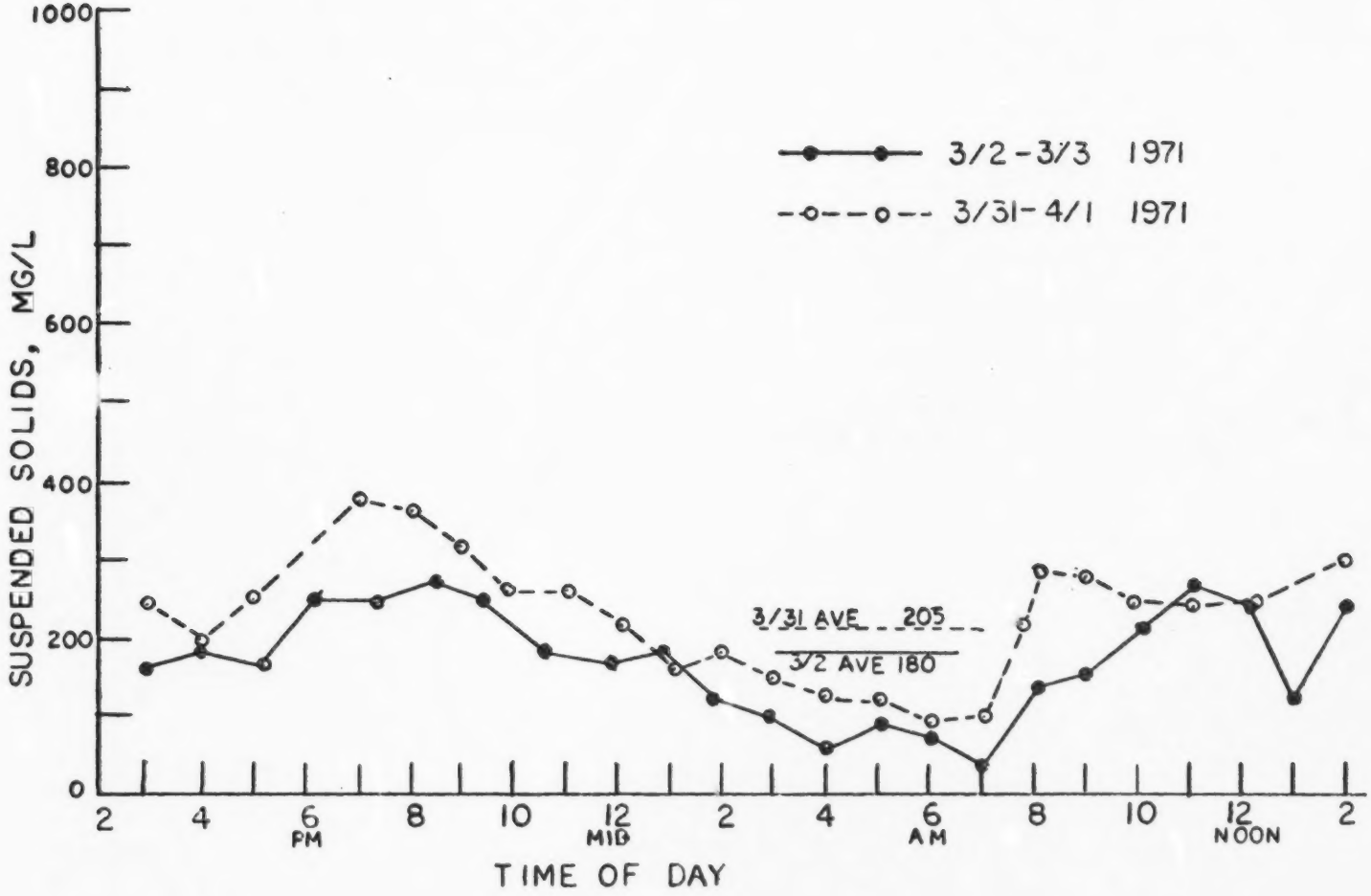

Fig. 9 SS Variations with Time, Manhattan Plant

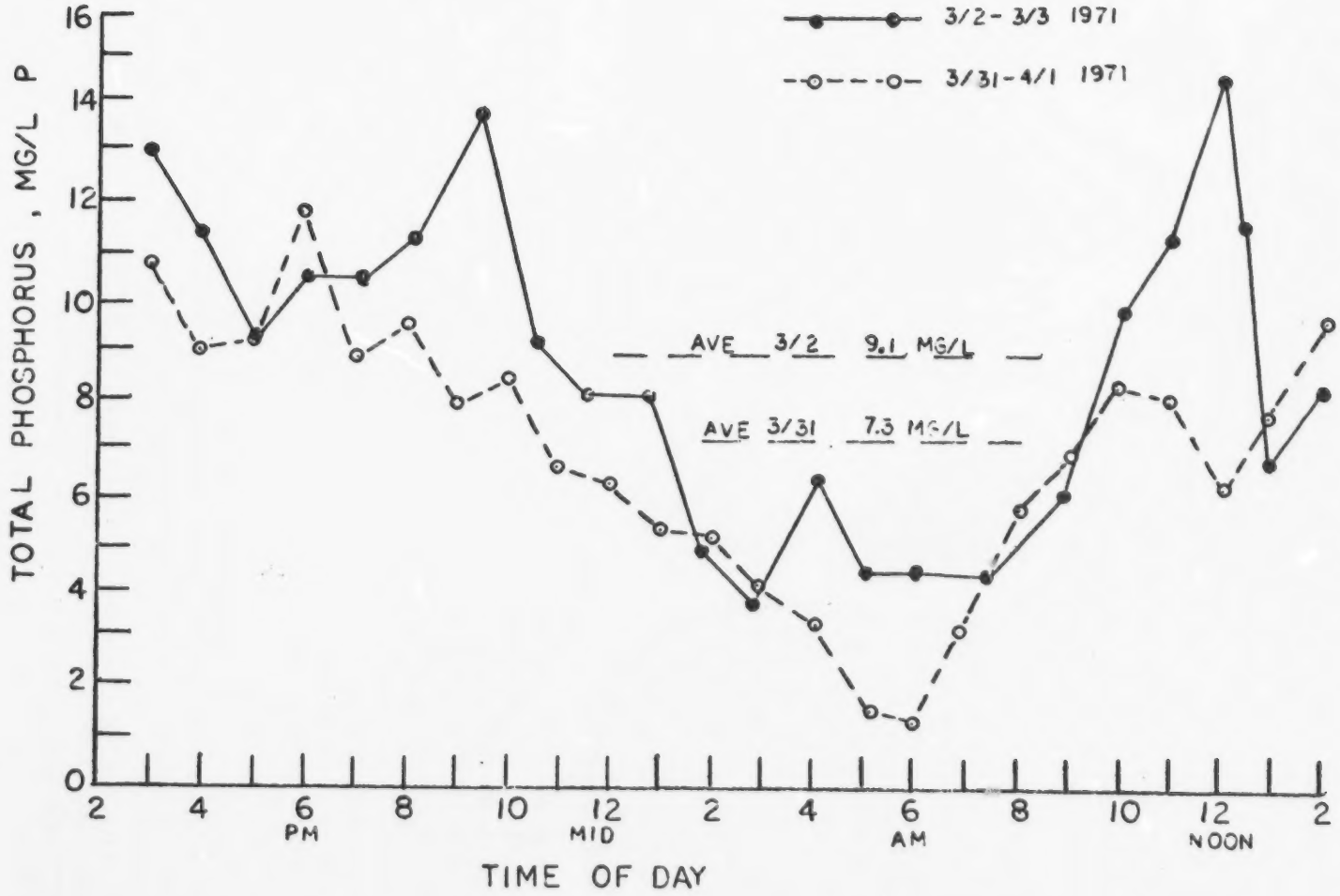

Fig. 10 Phosphorous Variations with Time, Manhattan Plant

Table 2. Alkalinity, pH, and hardness of Manhattan wastewater, composite values. Expressed as mg/l $CaCO_3$.

pH	Alkalinity	Calcium	Magnesium	Total Hardness
7.2	235	110	40	150

In general it appears that the Manhattan wastewater can be considered to be a very typical domestic sewage.

Effect of pH on Phosphorus Removal

Many variables of operation changed throughout the period of this study, flow rate, method of lime feed, method of pH control, temperature, waste characteristics, etc. The single factor that most affected phosphorus removal however was pH. This was expected since the mechanism of removal is by precipitation with the solubility of the calcium phosphate hydroxy apatite precipitate being a function of hydroxide ion concentration.

Over the period of the study the pH of the lime treated sewage was varied from slightly above neutral up to pH 11.4. Figure 11 is a plot of the phosphate removal through the primary system versus primary effluent pH for select runs. "Selected runs" refer to 24 hour samples which were collected at a time when the plant was known to be operating consistently for a period of several days prior to a sampling day. Problems were often encountered with flow, pH control, or lime feed and all of these systems had to be working for a period of time to obtain valid data.

Since most of the phosphorus is removed in the primary precipitation phase, it will be analyzed separately. Figure 11 shows some increase in removal as pH increases to 9, but it is quite slight. Between pH 9 and pH 10 phosphorus removal increases rapidly. Above pH 10 removal levels off rapidly and we get very little additional removal by increasing the lime dosage any further. The desired operating pH depends upon what removal is desired through the system. Operating pH's of around 10 are capable of 80 percent removals through the primary alone while operating at pH's of 11 or 11.5 could result in removals of 90 percent or better. At these higher pH's other factors occur to reduce the desirability of operating at high pH.

Even though soluble phosphorus was very low at a pH 10, it was difficult to get removal consistently above 80 percent. The reason for this was incomplete settling and floc carry over. Changing the flow rate and consequently the surface overflow rate of the primary clarifier, which varied by a factor of three during the study, did not seem to appreciably change the amount of this floc carry over. There was always some light fluffy floc particles of about pin head size that could be seen passing over the primary clarifier wiers.

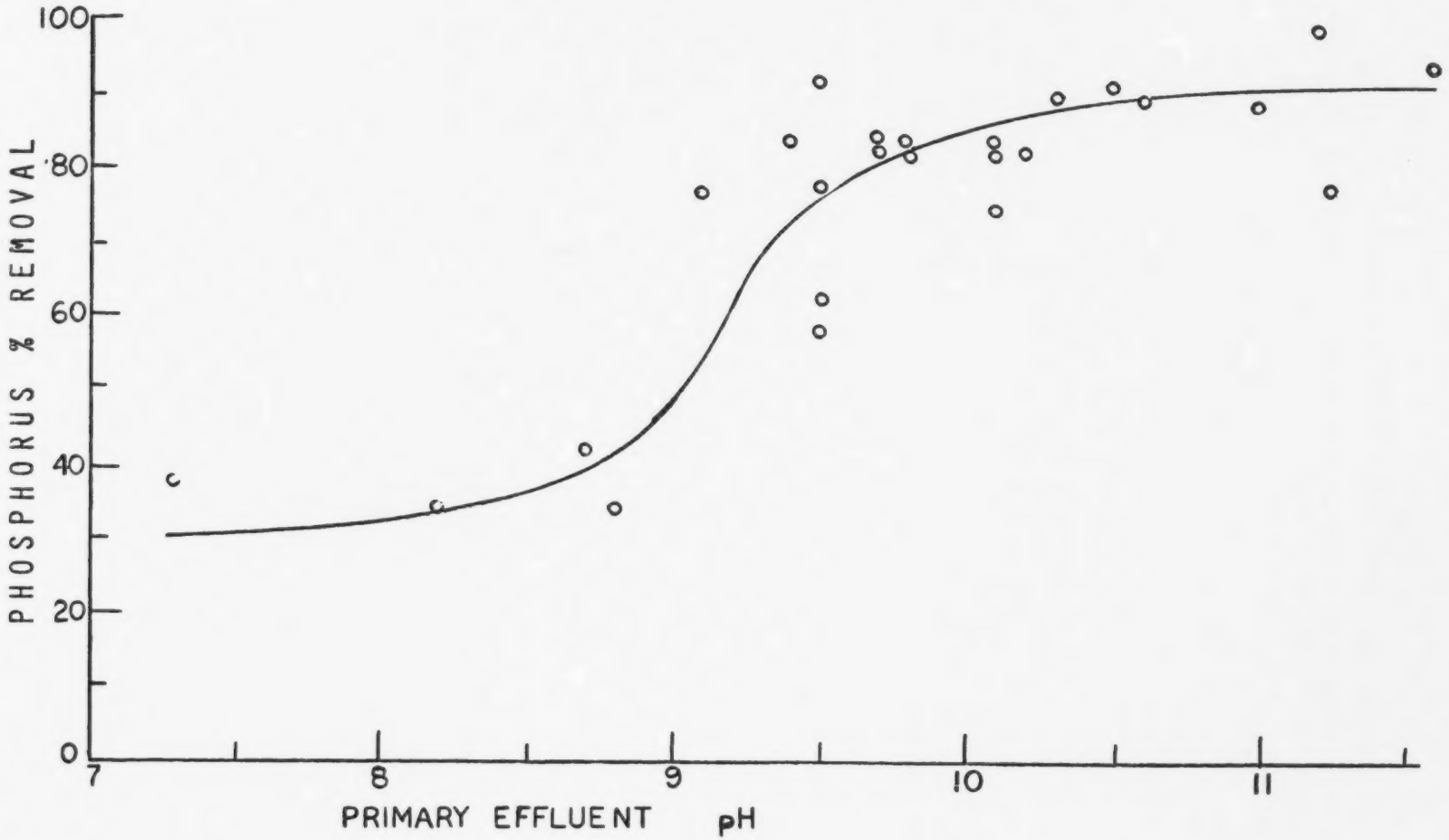

Fig. 11 Phosphorus Removal versus Primary Effluent pH

Phosphorus Removal through the Biological Process.

Removal of phosphorus through the secondary portion of the plant was much poorer than anticipated. For the data between pH 9.5 and pH 10.5 only an additional 2.5 percent removal was obtained through the biological portion of the plant. This can be explained partially by the nature of the plant. The final settling tank was a single hopper bottomed tank with an air lift sludge return. The tank had sides sloped 60 degrees and much trouble was encountered in getting solids returned from the secondary clarifier. Solids tended to hang up on the sides of the tank where they underwent anaerobic action and denitrification occurred. This resulted in much of the sludge floating to the surface of the clarifier. In general the final clarifier was usually anaerobic due to the inability to return solids properly. Anaerobic conditions tend to cause the release of some of the phosphorus that is either within or absorbed to the cells. Studies on the biological process for removing phosphorus have emphasized the need to return the sludge promptly and avoid anaerobic conditions unless you wish to strip the phosphorus from the sludge. The poor removal through the biological portion of the process is not considered to be a fault of the process, but instead is a fault in the plant design.

pH versus Lime Requirements.

Lime was purchased in 50 pound bags of high calcium, hydrated lime ($Ca(OH)_2$). Its strength was checked several times by titration against standard acid and it was found to average about 94 percent $Ca(OH)_2$. Lime was made up in a slurry form by mixing with tap water and was kept stirred by mechanical means. Lime dosage was determined by measuring the drop in lime slurry within the feed barrel. The decrease over a measured period of time was converted to weight of lime and was then divided by the total flow for the measured time to get mg/l of lime added. Figure 12 is a plot of some typical values showing lime dosage versus pH of primary effluent. The values given in Figure 12 are average values over 24 hours. Any instantaneous lime concentration demand to maintain a desired pH will vary throughout the day as the strength of the sewage changes and as the alkalinity may change. Some values giving an indication of this magnitude are presented in Table 3. These are for a time period of 2 days during which the pH was constant at pH 10.5.

Table 3. Lime Dosage Variations for Different Periods of the Day for a pH of 10.5.

Time Interval	Lime Dosage
8:30 a.m. - 4:30 p.m.	340 mg/l
4:30 p.m. - 8:00 a.m.	302 mg/l
8:00 a.m. - 2:30 p.m.	332 mg/l
2:30 p.m. - 4:30 p.m.	360 mg/l
4:30 a.m. - 8:30 a.m.	320 mg/l

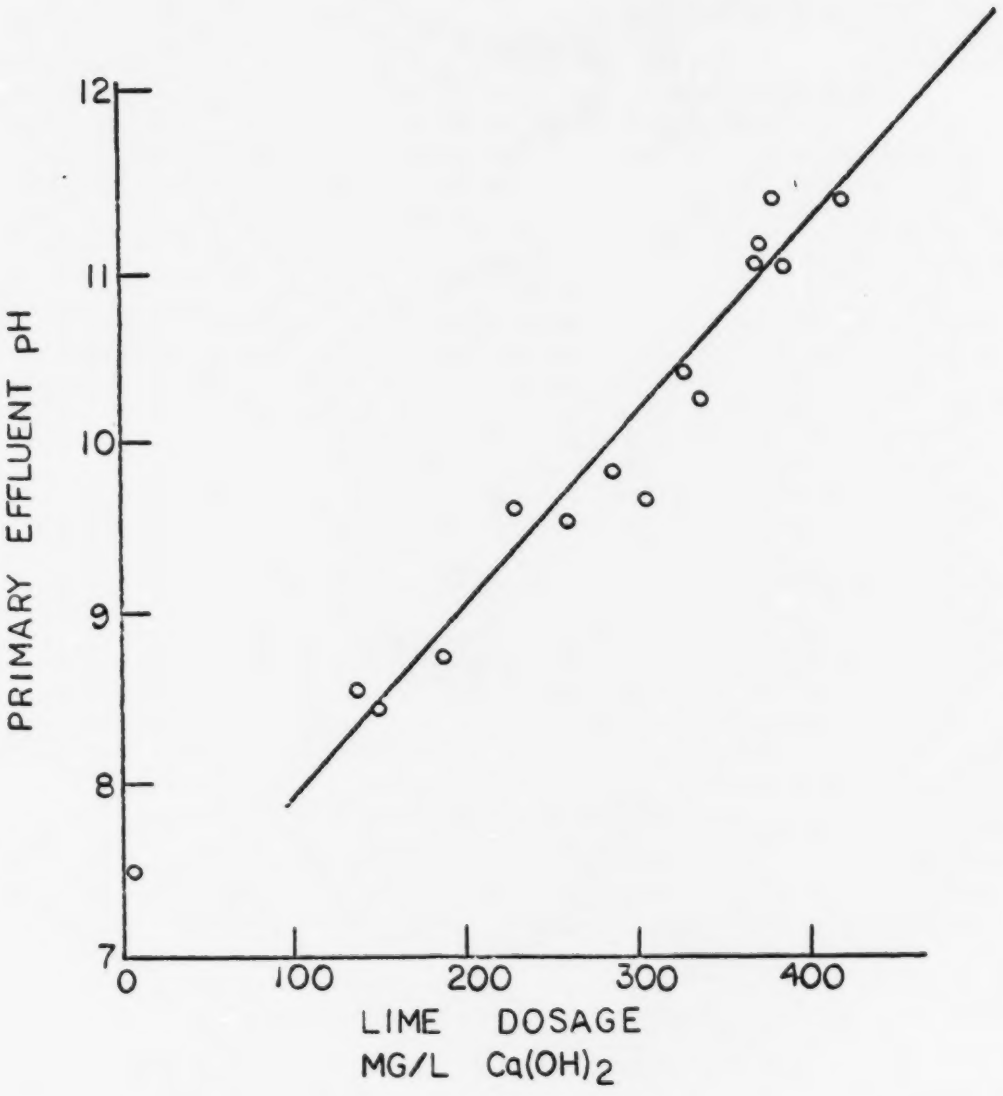

Fig. 12 Primary Effluent pH versus Lime Dosage

Lime Feed and pH Control

There are several alternatives to controlling the amount of lime to be fed to the process. This research explored these and found that several methods would work. The best method of course would be to have a pH sensor, recorder and controller to automatically increase or decrease the lime dosage to maintain a constant pH at all times. This was the method of choice in this project. However, as mentioned earlier, the design of the system did not allow the controller to function as it should and the pH at the sensor would overshoot the set point. The lime feed pump did not operate as a variable speed pump but instead was strictly an on-off pump. By the time the small portions of overlimed sewage and underlimed sewage reached the settling tank they were generally well enough mixed to give a resulting pH equal to the desired pH. This probably had some adverse effect upon the process but it was not felt to be great. Another method of lime feeding would be to have the lime be fed proportional to the flow. Thus, rather than be tied into a pH sensor the variable lime feed device could be connected into the plant flow measurement system for control. Table 3 showed that although lime demand did vary over the day it didn't vary greatly, less than $\pm$10 percent of the average. This system was used for many runs, especially when the pH meter or electrode system was under repair. This system was able to hold a constant pH nearly as well as the regular pH control system.

Another method would be to feed the same amount of lime over the entire day or possibly change it every four to eight hours. This would create the greatest variability due to both the varying flow and the varying strength of sewage, but it may have applications for small plants or under temporary conditions. The dosage could be set to give the desired pH at the maximum flow. This would result in overdosing at lower flows but it has been found that this process can handle overdoses very well. The major problem involved here is wastage of lime and increased production in sludge.

Changes in Other Waste Constituents with Lime Treatment

An additional benefit to be realized by lime treatment of raw sewage is the removal of waste constituents other than phosphorus. The removal of additional organic material from the primary system reduces the organic load in the secondary portion of the plant and may result in some cost savings for that portion of the plant. Lime has always been recognized as a coagulant aid. It was first used to treat sewage back in the mid 19th century (9). It was recognized at that time that lime combined with phosphates provided better clarification of sewage. Phosphates were added at some plants as a coagulant aid and a patent was issued for that process. Our present sewages do not require a phosphate addition since this has been added to sewage by way of the detergents. Lime treatment for clarification enjoyed a resurgence in this country in the mid 30's but again fell out of favor as biological processes began to be added which eliminated the need for additional treatment within the primary treatment.

Figures 13 and 14 plot COD and SS removals from the primary system versus pH, which correlates with lime dosage. COD removal shows a marked increase

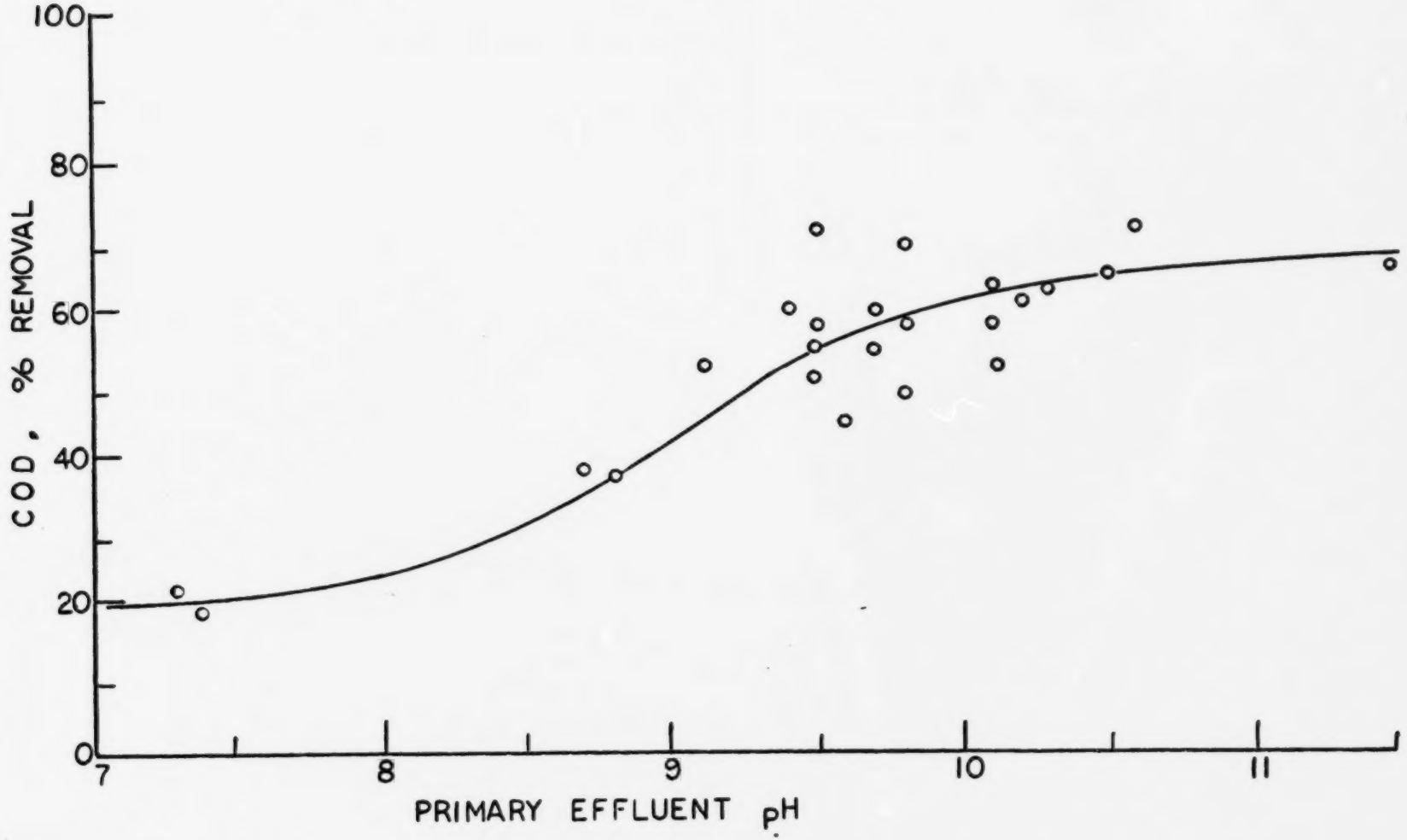

Fig. 13 Primary COD Removal versus pH

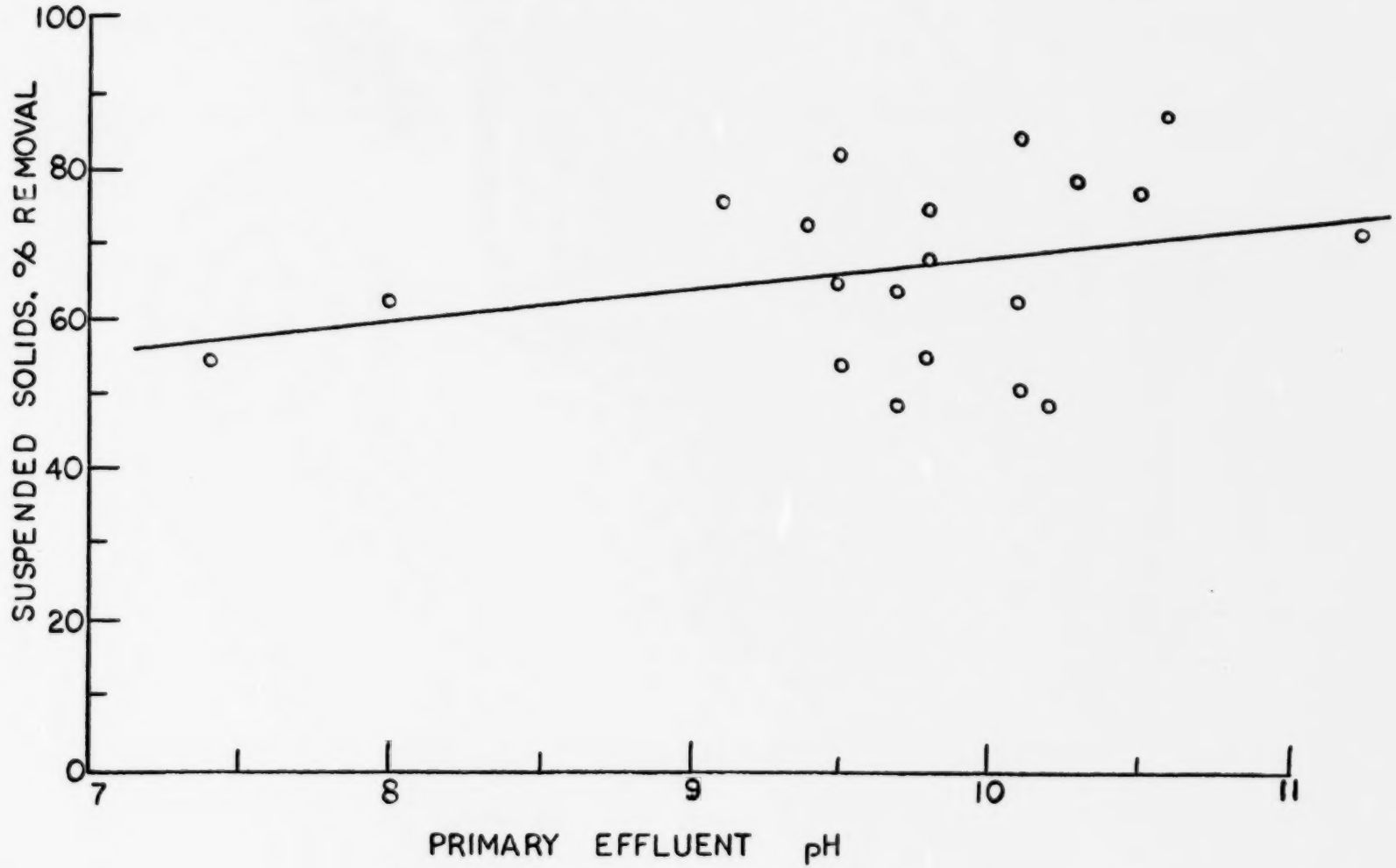

Fig. 14 Primary SS Removal versus pH

from about 20 percent to 25 percent COD removal without lime treatment up to a 60 to 70 percent removal at a pH of about 10.0. BOD values were not run continually like the COD's but the removal of BOD is roughly about the same as the COD removals. Suspended solids removal did not show a great increase in removal by the addition of lime. However, the solids in the primary effluent are not the same solids that entered the tank in the raw sewage. Primary effluent suspended solids appeared to be primarily precipitate carry over, the combination of the calcium phosphate and calcium carbonate precipitate. These solids would redissolve in the lower pH of the aeration tank. Even though the solids removal did not show an increase on a weight basis, the primary effluent with lime treatment was of considerably more clarity than the primary effluent without lime treatment. This is supported by observation of turbidity values. Turbidity values varied from around a low of 10 standard turbidity units (STU) in the early morning hours to a peak of about 40 STU in the late afternoon hours. Primary effluent without lime treatment would usually range over 100 STU during the day time hours. Table 4 gives some results of turbidity analyses for an operating pH of 9.4.

Table 4. Typical Turbidity Analyses at pH 9.4

Time	Settled Sewage	Primary Effluent Lime Treated	Final Effluent
9:00 a.m.	130	2	1
3:00 p.m.	150	54	4
9:00 p.m.	89	41	2
3:00 a.m.	45	28	1

There is little change in the weight of suspended solids in the primary effluent for lime treated versus non-treated sewage but yet the clarity with lime treatment is much better. This indicates that the smaller colloidal particles of the sewage are being removed and replaced by the larger chemical precipitate.

The effect of lime dosage on alkalinity, pH, and hardness can best be shown by a typical analyses run on a 24 hour composite sample. This is illustrated in Table 5.

Table 5. Effect of Lime Treatment on Chemical Characteristics Through Plant

Sample	pH	Calcium mg/l $CaCO_3$	Magnesium mg/l $CaCO_3$	Pheno. Alk	Total Alkalinity
Raw Sewage	7.1	96	36	0	202
Primary Effluent (Lime Treated)	9.6	136	36	80	232
Final Effluent	8.0	160	28	0	107

It should be pointed out that the composite is made from only four samples over a 24 hour period so that due to retention time through the units a completely accurate picture cannot be shown. This shows for example in the discrepancy between the calcium content of the primary effluent and the final effluent and yet no calcium is added within this stage.

The general conclusion from this and the rest of the data is that the hardness will be increased but not in direct proportion to the lime added. Some calcium carbonate will precipitate removing some of the added calcium. This is also supported by the reduction in total alkalinity from the raw sewage to the final effluent indicating that some of the bicarbonate has been precipitated as calcium carbonate.

Effects of Lime Treatment on the Biological Treatment Process

Laboratory research by the investigator in an earlier study (10) had shown that the buffering capacity of the aeration tank in a complete mixed system could handle fairly high primary effluent pH values. The results of this pilot study has supported this original claim completely.

The pH in the aeration tank was essentially the same as the final effluent at all times. The normal aeration tank pH with no lime treatment was about 7 to 7.2. Primary effluent pH values of about 9.5 resulted in aeration tank pH values of 7.5 to 8.0. Lime dosage was increased slowly over a period of several weeks until the lime treated sewage had a pH of only 8.5. It can be concluded then that the buffering capacity and the carbon dioxide produced by the metabolic activity is sufficient to neutralize the high pH values following lime treatment of sewage. The addition of lime treated sewage to an activated sludge system will have an affect upon the microbial life within the tank. Protozoa life, however, did not change from what would be considered a normal activated sludge distribution. The predominant species was ciliates and the population changed from free swimming ciliates to rotifers depending upon the organic load imposed upon the tank. A laboratory study consisting of batch feed units, one unit receiving settled sewage, the other

unit receiving lime treated sewage, was conducted during the course of the field study. This also helped provide a comparison between the sludges.

The activated sludge produced with lime treatment did not have the characteristic dark brown color usually associated with activated sludge. This sludge was instead a light brown-gold in color. This was especially noticeable in the laboratory units where a direct comparison could be made. The sludges in both the laboratory and the field units were more filamentous than the controlled laboratory unit receiving only settled sewage. This was a very fine filamentous growth which appeared to be actinomycetes. It was mixed in with normal appearing activated sludge flocs. The filamentous growth wasn't predominant but it was sufficient to result in bulking sludge. At times the pilot plant had sludge volume index values up to 600. A more normal value was a sludge volume of 300 which is about what was experienced in the laboratory unit also.

There was not real explanation found for this trend to sludge bulkiness. Iron shortage was suspected and iron was added to the aeration tank on a continuous basis for several weeks. This was at a concentration of 3 to 5 miligrams per liter of iron. The sludge volume index decreased drastically but it is felt that this was due to precipitation and weighting of the sludge rather than a change in the microbial nature of the mixed liquor suspended solids itself. Microscopic observation still showed the presence of about the same number of filamentous organisms. This increased density with chemical addition may provide a clue, however, to the reason for settling. The increased primary clarification due to lime treatment will remove more of the nonvolatile and heavier suspended solids than will conventional settling. This means that there is less build up of inert solids in the aeration tank. It is believed that these heavier inert solids may help the settling in the normal activated sludge process. Their absence from the lime treatment process means that even if the sludge was of the same microbial content it may settle slower. The mixed liquor volatile suspended solids content of the activated sludge in the lime treated process also supports this conclusion. Volatile solids values were generally in the range of 80% to 85%. This compares to 70% to 75% normally expected in conventional activated sludge and with about 75% found in the laboratory unit receiving settled sewage.

Sludge Production.

One of the major costs and problems generally associated with chemical treatment of sewage is the handling of the larger quantity of sludge that is produced. As mentioned earlier in the report primary sludge was pumped automatically on an intermittent basis by an air lift pump. This sludge was pumped into two 200 gallon tanks where an entire day's sludge could be accumulated. After 24 hours the volume was recorded. The tanks were then stirred and sampled. The values so determined were calculated as pounds of dry solids per million gallons of flow.

Sludge tended to hold up in the hopper bottom tank with the result that it was not always determined for certain that the sample collected included

the entire days production. The inside tank walls were hosed down at the start and finish of a sludge collection run in an attempt to assure better results.

A plot of primary sludge production versus pH of primary effluent is shown in Figure 15. This illustrates the rapid increase in sludge production with increasing pH. The calculated values shown for no lime addition is based upon the average raw sewage suspended solids concentration and an estimated suspended solids removal of 60%. At an operating pH of 9.5, over three times as much sludge will be produced with lime treatment as without. The volatiles solids content of this lime sludge averages between 45% and 50%. In comparison, the volatile solids content normally expected for sludge produced without lime treatment is in the range of 60% to 65%.

Sludge density is another important characteristic. The density of the sludge produced by lime treatment was generally about 3% after 30 minutes of settling. As will be discussed later, the addition of polymers to the sludge greatly increased this density.

Secondary Sludge Production.

Determination of biological solids production was a much more difficult thing. Sludge wasting was a very intermittent thing as for many periods of time solids lost in the effluent were sufficient to hold the mixed liquor suspended solids at a constant level. An estimate of this production was made by following the increase in mixed liquor suspended solids over a period of one to two weeks and using the average effluent suspended solids values. The biological solids production from four determinations made in this fashion for primary pH values between 9.5 and 10 were 42, 50, 46, and 55 or an average of 48 mg/l. These values were the production per pass through the aeration tank. Average COD of the primary effluent was 230 mg/l for these periods for a solids production to COD ratio of 0.208.

Assuming a BOD_5 to COD ratio of 0.42 for primary effluent after lime treatment, a figure substantiated from 10 samples for which BOD was run, the biological solids production could be estimated at about 0.5 pounds of biological solids produced per pound of BOD_5 added to the aeration tank. This figure is high but within the realm of reason. Sludge age values averaged about 12 to 15 days for a mixed liquor suspended solids level of around 2000 mg/l. This is a longer sludge age than normally encountered for aeration times of 8 to 10 hours, but it can be explained by the fact that a much lower strength waste is being used due to the pre-treatment procedures, and also that more of the inert non-volatile solids has been removed in the primary treatment system.

Sludge Treatment.

The lime treatment process produces considerably more sludge than what would be produced in a conventional treatment plant. The total sludge produced in a typical lime treatment process may total 3750 lbs per million gallons of which only about 7% by weight may be secondary sludge. In a conventional

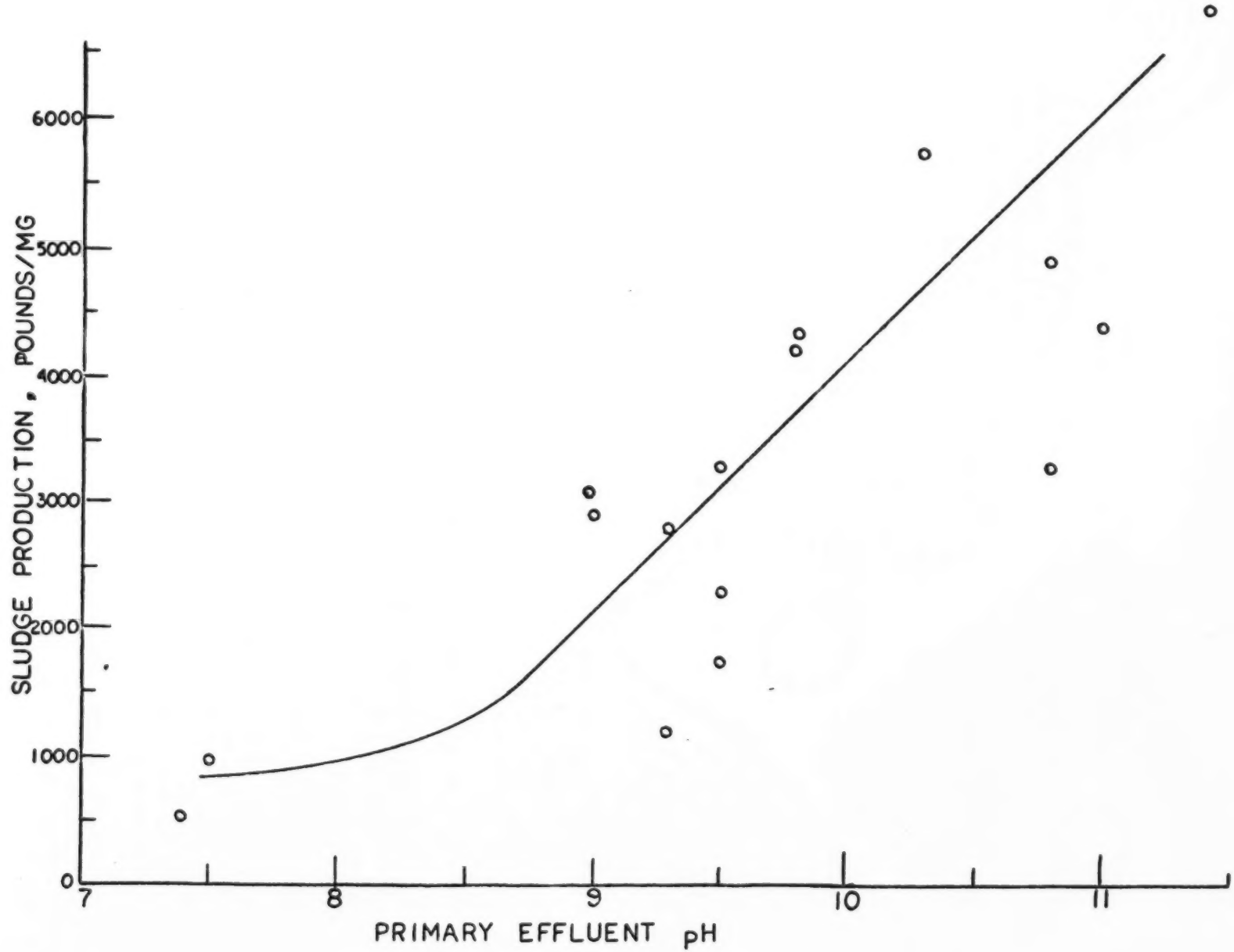

Fig. 15 Primary Sludge Production versus pH

plant total sludge production may be around 1500 lbs. per million gallons of flow of which over 35% by weight may be secondary sludge.

Lime sludge was found to dewater very well with proper polymer treatment. In the original laboratory research Dow A-21 was found to be about the only polymer that really worked well (10). Dow Chemical has replaced this with A-23 which works even better although the price per pound increased over that of the A-21. Figure 16 is a plot of filtration rate versus polymer dosage for lime sludge alone and for mixtures of lime sludge and waste activated sludge. This mixture is approximately the proportion that would be expected from a lime treatment plant. The mixing of activated sludge with the lime sludge results in a decrease in filtration rates. Whether this is entirely due to the solids themselves or mainly due to the diluting effect of the less concentrated activated sludge cannot be ascertained. However, even at the lower filtration rates for the combined sludge, filtration rates of 5 lbs/sf/hr can still be obtained for polymer dosages of 2.5 lbs/ton of dry solids. This is equivalent to a chemical cost for vacuum filtration of about $9 per million gallons of flow. This cost is within the range normally expected for dewatering a mixture of raw and activated sludge from a conventional plant. Biological solids are difficult to dewater by either vacuum filtration or centrifugation. The reduction of biological solids requiring treatment and the reduction in percentage of total sludge treated is a definite advantage of this process.

Ultimate sludge disposal may be by incineration or land fill directly. The use of anaerobic or aerobic digestion is not recommended for the treatment of this sludge. Either process could result in the release of some of the phosphate into the supernatant which would have to be treated again. The primary reason for not digesting this sludge, however, is that the chemical sludge would occupy too much digester volume. Digester requirements may have to be more than doubled in order to obtain the same degree of digestion.

The rapid concentrating effect and the conditioning for the dewatering of this lime sludge by Dow A-23 makes the large volume of chemical sludge produced in this process less of a liability than what might have been expected.

Effect of Lime Treatment on the Biodegradability of the Waste.

Observation of pilot plant data from this study revealed in the early runs that the treatment plant was achieving very good overall BOD and COD removals. Total BOD removals up to 98% were obtained, which is well above that normally expected in a biological treatment process. A laboratory study was set up to determine and compare the biodegradability of lime treated sewage versus settled sewage.

Some recent research has indicated that the lime treatment results in hydrolysis of the high molecular weight compounds with the result that resulting lower molecular weight compounds are more amenable to carbon absorption (11). Lower molecular weight compounds should also be more

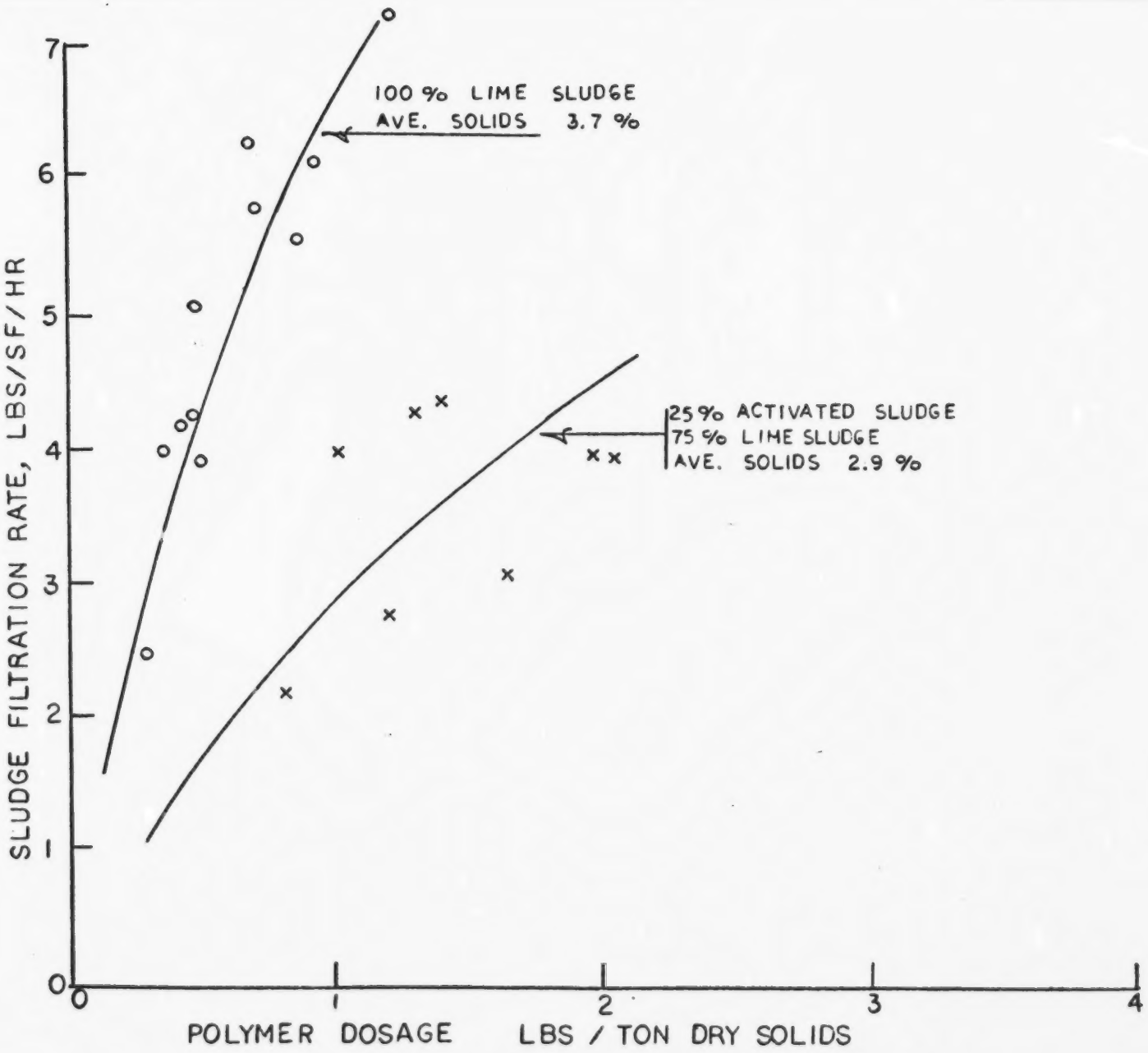

Fig. 16 Chemical Sludge Filtration Rate versus Polymer Dosage

amenable to biological treatment. Another theory is that more particulate and colloidal BOD is removed by lime coagulation leaving primarily a soluble readily degradable material. These theories were explored by laboratory determinations of k_1 rates (BOD reaction rate constant) by means of a Warburg apparatus.

Two 3-liter laboratory activated sludge units were maintained on a batch feed basis. One unit received settled sewage from the Manhattan wastewater treatment plant while the other unit received lime treated sewage from the pilot plant. Each day 1.5 liters were decanted off following settling and replaced with either the settled sewage or the lime treated sewage.

It was theorized that the biological solids which were developed on lime treated sewage could also have an effect on the biodegradability, so the experiment was designed to explore this effect also.

Three different operating pH values were used; 9.8, 10.5, and 11.5. Raw sewage was treated with lime to these pH values flocculated and the supernatant decanted. The different combinations used were settled sewage with microbial solids grown on lime treated sewage, settled sewage with microbial solids grown on settled sewage, lime treated sewage with microbial solids grown on lime treated sewage, and lime treated sewage with microbial solids grown on settled sewage. All microbial solids were thoroughly washed of any remaining substrate before addition to the Warburg flasks. A detailed description of the research procedure is presented by Flournoy (12).

Table 6 summarizes the results of this study. The k_1 values reported are to the base 10. Corrected values refer to the fact that the uptake rates were corrected for endogenous respiration as measured by an unfed blank. Table 7 shows the ratio of k_1 values of lime treated sewage to that of settled sewage. The values are the average of three separate runs at each pH. The term SS solids refers to microbial solids developed on settled sewage while lime solids refers to the use of microbial solids developed on lime treated sewage.

This data shows that the k_1 value, the BOD reaction rate constant, is increased significantly by lime treatment. This would mean that the effluent from lime treatment is more biodegradable than the effluent from conventional settling. However, the thesis that the microbial solids developed on lime treated sewage may aid in this increased removal proved to be false. In fact, there seemed to be a definite relationship the other way, indicating that microbial solids developed in this substrate were not as efficient.

Because these two conclusions tend to nullify each other, the only real conclusion that can be made is that the biological process is not significantly altered by prior lime treatment of the waste. However, this in itself is a significant conclusion.

TABLE 6. The k_1 Reaction-Rate Constants

Runs	Lime Treated Sewage pH[1]	MLSS Conc.[2] mg/l	Final Suspended Solids Conc. in Mixture mg/l	Combinations							
				Uncorrected				Corrected			
				SS Solids		Lime Solids		SS Solids		Lime Solids	
				SS	Lime	SS	Lime	SS	Lime	SS	Lime
1a	9.8	1000	200	.36	.75	.49	.67	.43	.86	.63	.85
1b	9.7	2000	400	.64	.69	.86	1.01	.72	.96	1.93	1.15
1c	9.8	3000	600	.98	1.37	.88	1.04	1.29	1.86	.89	1.15
2a	10.5	1000	200	.41	.87	.23	.47	.49	1.12	.22	.42
2b	10.5	2000	400	1.06	1.29	.42	.28	----	----	----	----
2c	10.5	3000	600	1.07	1.15	.93	1.00	.97	1.3[illegible]	.97	1.04
3a	11.5	1000	200	.54	.90	.48	.22	.63	1.23	.48	.29
3b	11.5	2000	400	1.00	1.31	.73	1.08	1.00	1.89	.77	1.25
3c	11.5	3000	600	1.28	1.47	.61	.69	----	----	----	----

[1]Before neutralization.

[2]Conc. of 1 ml activated sludge solution added to flask.

TABLE 7. Ratios of Lime Treated Sewage k_1 Values to Settled Sewage

Run	Lime Treated Sewage pH(1)	MLSS Conc(2) mg/l	SS Solids	Lime Solids
1a	9.8	1000	2.1	1.4
1b	9.7	2000	1.1	1.2
1c	9.8	3000	1.4	1.2
Average			1.5	1.3
2a	10.5	1000	2.1	2.0
2b	10.5	2000	1.2	0.7
2c	10.5	3000	1.4	1.1
Average			1.6	1.3
3a	11.5	1000	1.7	0.5
3b	11.5	2000	1.3	1.5
3c	11.5	3000	1.1	1.1
Average			1.4	1.1

[1] Before Neutralization.

[2] Conc. of one activated sludge solution added to flask.

MISCELLANEOUS STUDIES

Addition of Polyelectrolyte to Increase Primary Clarification.

Difficulty was encountered in obtaining removals of phosphorus of greater than 80% from the primary portion of the plant. As was discussed earlier the major carry over of phosphorus was not due to soluble phosphorus but unsettled precipitate which appeared as pin point flocks. It had already been demonstrated that the Polymer Dow A-23 worked very well in treating this lime sludge for dewatering. If was theorized that the addition of polymer immediately after lime addition would aid in coagulation. Polymer addition was tried at several points of the process from before lime addition to just prior to where the flow entered the primary tank. The best point, as determined by floc observation, was immediately after lime addition.

A two week series of polymer addition was initiated with lime dosages set to give a resultant pH of about 10. The polymer dosage was increased until a visual difference could be discerned in the floc. This required a dosage of about 1 mg/l of Dow A-23. A dosage of 1.5 mg/l was selected for the run. Over a two week period there appeared to be a slight improvement in the phosphorus removals and the suspended solids removals but there was not enough improvement to establish a statistically reliable difference. A polymer dosage of 1.5 mg/l would require 12.5 pounds of polymer per million gallons of flow for a cost of $25 per million gallons. This is more than the lime cost alone. It was hoped that some of this polymer cost could be recovered by the reduced requirement for polymer for sludge conditioning. This was not the case, however. Apparently, the long retention time with this biologically active raw sludge reduced the effectiveness of this polymer for sludge dewatering. Approximately the same amount of polymer had to be added to dewater as was required to dewater the lime sludge alone. The polymer addition was increased to 2.5 mg/l with no apparent increase in performance.

The conclusion can definitely be drawn that addition of this polymer with the lime was of no economic benefit.

Primary Sludge Recirculation.

Recirculation of chemical sludge to improve clarification has long been practiced in the water treatment industry. A short study was undertaken in this research to determine if primary sludge recirculation would aid in chemical reduction and phosphorous removal. The sludge was pumped from the primary clarifier hourly into the 200 gallon sludge storage tank. Sludge was pumped from the bottom of this tank by a rubber impellered Jabsco pump, the same model as used for pumping raw sewage to the plant. A variable speed motor driving this pump allowed the sludge to be pumped back into the influent line just prior to where it entered the primary clarifier. Trouble was encountered with the mechanics of the system but it was operated off and on for three days. The sludge return rate was high, about 50% of the raw flow so retention time within the settling tank was effectively reduced. Only several grab samples were obtained for this time. Continuous turbidity

monitoring and soluble phosphorous monitoring showed no improvement in the primary effluent. Lime dosage remained the same to allow a pH of about 10. After about the second day of recirculation, with some waste to take care of sludge produced, the sludge became more septic and the primary effluent worsened. By visual observation it was noted that the primary effluent was more turbid and flocculation was poorer with the sludge recirculation.

This portion of the study had to be dropped due to failure of the mechanical equipment. It is realized that because of the shortness of this study that definite conclusions cannot be drawn but it is worth mentioning because of its implications. This sludge is not an inert chemical sludge as is normally encountered in water treatment. It is instead a mixture of a highly putrescible organic sludge and a chemical sludge. Recirculation of this type of sludge would greatly lengthen the time that this putrescible portion of the sludge would remain in contact with the carriage water. Decomposition of this organic matter results in a solubilization which would tend to release organic matter, or BOD, back into the system. With recirculation of this high solids sludge at the low strength night time flows it would appear that it would be possible to have an effluent worse than the influent.

Ideally, it would appear that the chemical sludge and raw sewage solids mixture should be removed from the primary tank as rapidly as possible and not be returned as a recirculated sludge.

DISCUSSION

Lime treatment of raw sewage prior to biological treatment appears to offer one solution to the removal of phosphorus from sewages. The process is capable of consistent removals in the area of 80% but it cannot be relied upon if removal greater than this is consistently desired.

Lime control is best done with a control system which will allow for a constant pH. It was found that maintaining a constant pH is not highly critical in this process. As long as the pH is above 9.5 good removals will occur. About the only detriment caused by a lime overdose is an increase in sludge and a wastage of lime. The biological process following lime treatment is not highly sensitive to these changes in pH as long as the primary effluent stays below pH 11. This process involved a complete mix activated sludge system. A conventional system or a contact stablization system would be expected to be more susceptible to this higher pH because the waste would not be distributed over the entire tank contents. Even though more care would need to be exercised with these other biological treatment systems, it is felt that this process could still be used. This could also include the trickling filter treatment method.

The production of carbon dioxide by microbial life within the aeration tank is sufficient to neutralize the excess lime from the chemical treatment phase. Effluent pH values were below pH 8.5.

Lime treatment prior to biological treatment will result in a change of the microbial life within the aeration tank as compared to what it would be without lime treatment. This was evidenced by changes in the sludge appearance and also by an increase in the sludge volume index. Although the sludge volume index was about three times that normally expected it did not result in any major problems in the operation of the plant.

The major disadvantage of this process is the larger quantities of sludge which is produced. Any other chemical precipitation process for phosphorus removal also suffers this problem. Sludge production, including the chemical primary sludge and the waste activated sludge is about two and one-half times greater than for a comparable plant operating without phosphorus removal.

This sludge is, however, easily dewatered by chemical treatment. The recommended sludge treatment scheme would be polymer treatment, vacuum filtration or centrifugation, and then land fill or incineration.

Many plants use anaerobic digestion followed by some form of ultimate sludge disposal. The effect of this chemical sludge upon the anaerobic digestion process was not a part of the study. The major detriment would probably be the decrease in digester volume due to the inert chemical sludge. The chemical sludge should result in a well buffered system within the digester. Some solubilization and return of phosphorus to the system by digesters

supernatant return is quite likely, but the high ion concentration of calcium and phosphorous in this sludge should prevent most of it from solubilizing. This is an area which requires further study.

This process is very applicable where phosphorus removal is required at existing plants. Relatively little modification is required to existing facilities. Lime storage, lime feeding and pH control equipment need to be added. The existing tanks can be utilized. What additional needs to be done to handle the increased sludge would vary with each individual plant. This research has shown that this process is one that should be considered when phosphorus removal is required. The final process to be used should be selected only after bench scale or pilot scale tests have been completed with the waste in question.

ACKNOWLEDGMENTS

The support of the city of Manhattan, Kansas, for providing the site for the project, the utilities and the wastes is gratefully acknowledged.

Special thanks must go to Virgil Spain, Superintendent of Waste Treatment and his crew for helping in the operation of the plant and in collection of the many samples.

Mr. Ralph Flournoy, graduate student, performed many of the analyses and assisted in the research.

The support of the project by the Office of Research and Monitoring, Environmental Protection Agency and the Grant Director, Mr. Ed Barth, is acknowledged with sincere thanks.

REFERENCES

(1) Lea, W. L., Rohlich, G. A., and Katz, W. S. "Removal of Phosphates from Treated Sewage," Sewage and Industrial Wastes, 26, 261 (1954).

(2) Malhotru, S. K., Lee, G. Fred, Rohlich, G. A. "Nutrient Removal from Secondary Effluent by Alum Flocculation and Lime Precipitation," Int. Journal of Air and Water Pollution, 8, 487 (1964).

(3) Bogan, R. H., Albertson, O. E., and Pluntze, J. C., "Use of Algae in Removing Phosphorus from Sewage," Journal of the Sanitary Engineering Division, ASCE 86, No. SA5 (Sept. 1960).

(4) Vacker, D., Connell, C. H. and Wells, W. N., "Phosphate Removal Through Municipal Waste Water Treatment at San Antonio, Texas," Journal WPCF, 39:5:750 (1967).

(5) Levin, G. V. and Shapiro, J., "Metabolic Uptake of Phosphorus by Waste Water Organisms," Journal WPCF, 37:6:800 (June 1965).

(6) Ekerhardt, W. A., and Nesbitt, J. B., "Chemical Precipitation of Phosphate within a High Rate Bio-Oxidation System," Proceedings 22nd Annual Purdue Industrial Waste Conference, Lafayette, Indiana (1967).

(7) Nesbitt, J. B., "Phosphorus Removal--The State of the Art," Journal WPCF, 41:5:701 (1969).

(8) Schmid, L. A., "Look What $25 Can Buy," Water and Wastes Engineering, Vol. 8, No. 9 (Sept. 1971).

(9) Pearse, et al., "Chemical Treatment of Sewage," Sewage Works Journal, 7, No. 6, p. 997 (1935).

(10) Schmid, L. A., McKinney, Ross E., "Phosphate Removal by Lime Biological Treatment Scheme," Journal WPCF, 41:7:1259 (1969).

(11) Zuckerman, M. M., and Molof, A. H., "High Quality Reuse Water by Chemical-Physical Wastewater Treatment," Journal WPCF, 42:3:437 (1970).

(12) Flournoy, Ralph, "The Effect of Lime Treatment of Sewage on Oxygen Uptake by Activated Sludge," M.S. Thesis, Kansas State University, 1970.

Preceding page blank

APPENDIX

Preceding page blank

TABLE A-1. Pilot Plant Operating Data for Selected* Runs

DATE	TIME	FLOW	RAW SEWAGE			PRIMARY EFFLUENT							MLSS	FINAL EFFLUENT					
			COD	SS	P	COD	%R	SS	%R	P	%R	pH		COD	%R	SS	P	%R	pH
6/24	COMP**	6500	316	254	9.6	159	50	92	64	2.6	72	9.3	2150	21	93	20	2.6	74	7.9
7/ 6	COMP	10000	485	260	14.2	151	69	83	68	2.3	84	9.8	2700	15	97	11	1.8	87	8.5
7/ 8	COMP	8000	300	300	11.5	170	43	74	75	1.9	82	9.8	2050	10	97	8	2.0	82	8.1
7/22	COMP	8500	437	151	12.4	177	60	54	64	2.9	77	11.5	4025	40	91	4	2.9	77	8.2
7/27	COMP	10750	399	178	14.1	179	55	81	55	4.2	70	11.2	1800	30	93	16	3.0	78	8.1
8/ 4	COMP	11500	385	179	11.0	303	21	132	26	6.8	38	7.3	2750	63	84	44	12.2	--	7.2
8/17	COMP	13000	360	215	14.4	146	59	69	68	2.8	81	11.0	2460	35	90	34	1.7	89	8.2
10/19	COMP	14000	410	200	14.8	175	57	68	66	3.2	78	9.5	1590	32	92	4	2.5	84	8.1
10/20	COMP	14000	472	195	13.4	181	62	62	68	2.5	81	9.5	1590	32	93	4	2.1	85	---
10/27	COMP	14000	469	205	12.7	189	60	78	51	3.1	76	9.3	2590	22	96	4	2.7	79	8.0
12/21	COMP	11500	442	150	12.6	251	43	204	--	5.7	55	9.4	1770	28	94	18	3.5	73	7.8
1/25	COMP	10750	445	192	13.2	275	38	157	20	7.6	42	8.7	1800	20	96	15	6.0	54	7.1
2/18	COMP	10000	359	90	10.0	202	44	84	76	1.1	89	10.7	1500	40	89	--	1.3	87	8.0
3/31	1500	8000	600	190	10.0	204	66	60	68	1.3	86	9.5	4000	82	86	36	2.8	73	7.3
	2100	7000	662	240	8.6	249	62	60	75	1.4	83	9.2	----	61	91	2	2.0	77	7.5
	0300	4000	280	70	7.5	196	31	40	43	1.2	83	9.4	----	53	81	10	2.3	66	7.5
	0900	5000	345	140	7.0	147	59	16	88	1.3	81	9.5	----	61	82	6	2.1	69	7.7
	COMP	6300	512	174	8.5	204	60	48	73	1.3	84	9.4	4000	66	87	16	2.3	73	7.5
4/ 5	1500	9000	530	250	10.8	209	61	112	55	2.1	81	10.1	1660	82	85	24	1.6	85	7.5
	2100	6000	582	270	6.9	205	65	112	59	1.6	76	10.1	----	45	92	16	1.3	81	7.4
	0300	3000	332	130	6.6	213	36	296	--	1.2	82	10.2	----	37	88	18	1.5	77	7.4
	0900	5000	448	270	12.2	145	68	68	75	1.4	89	10.4	----	49	89	18	1.4	88	7.5
	COMP	5500	500	244	9.6	195	61	126	48	1.7	82	10.2	1660	59	88	20	1.4	84	7.5

Selected* Runs when all systems were functioning properly

COMP** Composite value

Table A-1 Continued

			RAW SEWAGE			PRIMARY EFFLUENT								FINAL EFFLUENT					
DATE	TIME	FLOW	COD	SS	P	COD	%R	SS	%R	P	%R	pH	MLSS	COD	%R	SS	P	%R	pH
4/ 7	1500	11000	508	280	8.9	189	63	124	56	4.0	55	9.8	1790	15	97	18	3.1	65	7.5
	2100	10000	533	290	10.8	196	63	128	56	5.4	50	9.7	----	41	92	50	2.9	73	7.4
	0300	5000	196	90	8.0	171	13	96	--	3.6	49	9.8	----	15	92	20	3.0	63	7.4
	0900	5500	234	260	9.2	133	43	68	74	3.5	61	9.9	----	48	80	62	3.4	63	7.4
	COMP	7940	422	250	9.4	179	58	111	56	4.3	54	9.8	1790	29	93	36	3.1	67	7.4
4/19	1500	10000	708	230	13.0	228	68	60	74	2.2	83	9.9	2425	80	89	14	1.3	90	8.3
	2100	8500	745	290	11.9	252	66	124	57	1.6	86	9.8	----	40	46	4	2.2	82	8.1
	0300	5500	284	50	8.9	208	27	76	--	2.2	75	10.7	----	32	89	4	2.6	71	7.9
	0900	4000	348	180	8.9	124	64	20	90	2.7	70	11.1	----	40	89	16	1.2	87	7.9
	COMP	7130	585	206	11.3	216	63	77	63	2.1	82	10.1	2425	53	91	9	1.8	84	8.1
5/ 4	1500	12000	545	160	14.0	235	57	64	60	2.9	89	9.0	1030	72	87	34	3.5	75	7.2
	2100	12000	510	170	11.9	255	50	32	81	3.1	74	9.1	----	56	89	20	3.3	72	7.1
	0300	12000	247	80	6.8	163	34	8	90	1.9	72	9.1	----	64	74	4	2.1	68	7.2
	0900	12000	454	150	9.5	171	62	28	81	1.7	82	9.0	----	60	87	14	1.7	82	7.4
	COMP	12000	439	140	10.5	206	53	33	76	2.4	77	9.1	1030	63	86	18	2.7	75	7.2
5/ 6	1500	10000	705	210	11.1	192	73	64	70	1.1	91	9.4	1075	43	96	4	0.7	96	7.2
	2100	10000	655	230	13.7	212	68	40	83	0.8	94	9.4	----	24	94	4	0.8	94	7.2
	0300	10000	357	140	7.1	98	73	12	92	0.3	95	9.5	----	51	86	8	0.5	98	7.4
	0900	10000	451	230	7.4	114	74	28	88	0.9	87	9.9	----	67	85	66	1.3	82	7.9
	COMP	10000	542	203	9.9	154	72	36	82	0.8	92	9.5	1075	46	92	20	0.9	91	7.4
5/10	1500	9000	450	210	17.2	309	31	136	35	6.9	40	9.4	1220	73	84	4	1.7	90	7.8
	2100	10000	506	120	14.2	225	56	88	27	1.9	87	10.2	----	45	99	4	2.1	86	7.6
	0900	9000	354	170	7.9	96	73	32	81	0.4	96	10.8	----	45	87	16	1.0	88	7.8
	COMP	9500	437	167	13.3	209	52	85	49	3.1	77	10.1	1220	54	88	8	1.6	88	7.7
5/13	1500	6000	628	220	15.3	189	70	44	80	1.6	89	10.0	1210	52	92	12	0.9	94	7.9
	2100	7000	408	120	12.9	198	51	68	43	1.3	90	10.6	----	42	90	8	1.1	92	7.8
	0900	5000	398	220	8.3	115	71	20	91	0.5	95	10.8	----	63	84	2	0.9	89	8.2
	COMP	6000	478	187	12.1	167	65	44	77	1.1	91	10.5	1210	52	89	7	1.0	92	7.9

Table A-1 Continued

			RAW SEWAGE			PRIMARY EFFLUENT								FINAL EFFLUENT					
DATE	TIME	FLOW	COD	SS	P	COD	%R	SS	%R	P	%R	pH	MLSS	COD	%R	SS	P	%R	pH
5/18	1500	7000	437	310	12.5	156	64	56	82	1.5	88	9.8	1590	30	94	12	1.0	92	7.7
	2100	6000	346	110	11.1	183	47	68	38	1.3	88	10.0	----	33	90	4	0.9	92	7.9
	0300	6000	193	70	5.8	140	28	60	24	1.3	78	9.6	----	30	85	14	1.9	67	8.1
	0900	5000	447	160	7.7	146	77	48	70	2.3	70	9.5	----	37	92	10	1.0	87	8.0
	COMP	6000	348	162	9.2	156	55	58	64	1.6	83	9.7	1590	32	91	10	1.2	87	7.9
5/24	1500	5000	831	360	10.6	269	67	68	81	1.3	88	9.7	2010	62	93	20	0.9	91	7.7
	2100	5000	508	130	9.0	223	56	40	69	0.9	90	10.5	----	154	70	10	0.9	89	7.9
	0900	5000	438	60	6.6	169	62	14	77	0.3	96	10.8	----	131	70	10	0.8	87	7.9
	COMP	5000	592	183	8.8	220	63	41	78	0.8	91	10.3	2010	116	80	13	0.9	90	7.8
5/27	1500	8000	512	260	8.5	179	65	104	49	1.4	83	9.7	1870	37	93	8	1.7	80	7.2
	2100	8000	351	140	7.7	---	--	176	--	1.5	81	9.7	----	37	89	6	1.6	80	7.4
	0300	8000	351	130	6.7	179	49	48	63	1.0	86	9.7	----	45	87	4	1.5	77	7.4
	0900	8000	399	190	7.1	116	71	44	77	1.0	86	9.6	----	45	88	8	1.5	78	7.5
	COMP	8000	403	180	7.5	160	60	93	63	1.2	84	9.7	1870	41	90	7	1.6	79	7.4
6/ 7	1500	12000	758	490	12.0	153	80	60	87	1.1	91	10.6	2775	15	98	5	0.9	93	7.1
	2100	10000	534	310	8.4	138	74	44	86	1.2	85	10.3	----	15	71	5	0.9	89	7.3
	0300	6000	273	310	6.8	111	59	20	36	0.8	72	10.8	----	8	97	4	1.1	84	7.4
	0900	6000	146	200	3.7	100	32	--	--	0.2	97	11.0	----	35	76	5	1.0	72	7.4
	COMP	8500	428	328	7.6	125	71	41	88	0.8	90	10.6	2775	18	96	5	1.0	87	7.3